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Proceedings of

# WATERSHED '89

## A Conference on the Stewardship of Soil, Air, and Water Resources

Juneau, Alaska
March 21 through 23, 1989

# PROCEEDINGS OF WATERSHED '89

## A Conference on the Stewardship of Soil, Air, and Water Resources

Juneau, Alaska
March 21-23, 1989


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# FOREWORD

Watersheds have natural boundaries. Accordingly, Watershed '89 focused on the nonpolitical aspects of soil, air, and water management. In March 1989, approximately 80 scientists from southern Alaska and adjacent British Columbia gathered in Juneau to exchange ideas and information on watershed management. A few watershed scientists from Washington, Oregon, California, and the interior of Alaska also attended the conference.

Representatives from state and federal agencies and private corporations were invited to present their concerns and perspectives. These talks were followed by a panel presentation and discussion on "Biodiversity and Watershed Management". The remainder of the conference consisted of volunteered presentations, including 8 posters.

The volunteered presentations covered a broad spectrum of disciplines and interdisciplinary issues. The papers from these presentations were reviewed by at least one, generally two or more, conference attendees before being accepted for publication in these Proceedings. Sixteen papers were submitted, as well as abstracts of nine others. No papers were rejected. A few speakers declined to submit papers or abstracts.

The Watershed '89 topics included ecology, soils, hydrology, wetlands, riparian areas, streams, fisheries, erosion, cumulative effects, seedling response to watershed conditions, and ecosystem carbon in a global perspective. The subjects of mass wasting, streams, and fisheries received the most coverage. Soils and wildlife habitat received less emphasis. Due to the interdisciplinary nature of watershed management and studies, the talks do not sort into discrete categories. The papers are grouped differently in the Proceedings than from the order presented.

We are grateful to the Federal, State, Provincial, and private organizations and individuals for participating in the conference. We were pleased with the invited speakers, the panel chair and members, the wide range of pertinent papers volunteered for Watershed '89, and the enthusiasm and participation of all attendees.

Max Copenhagen
Watershed Group Leader
Alaska Region, USDA Forest Service

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# Common Goals For Stewardship of Alaska's Watershed Resources

*W. G. Edwards*

*USDA Forest Service, Juneau, AK*

Good morning! Welcome to Juneau and the Alaska Region!

Right now this is the most exciting place I know of to be working in natural resource management. We're a big state with a small population and an incredible abundance and diversity of natural resources - wildlife, timber, fish, natural beauty and mineral wealth. Our Canadian friends occupy a similar position in their country.

At least in Alaska, we sometimes wonder if we have more help than we need as we manage these resources for the good of our citizens. The State is in center stage when it comes to resource and environmental issues. Right now there are several legislative proposals in the US Congress which deal with Alaska issues. They cover the range of concerns -- from timber harvesting and global warming -- to additional wilderness -- to further energy development in the Arctic. We're a focus of national attention by the whole spectrum of viewpoints in our society -- from preservation through development. Our role is to somehow sort all this out and manage the land so a proper balance is achieved between protection and use of its abundant resources. I can guarantee you it is a real challenge! That's why we are hosting this Watershed '89 Conference.

We are about to kick off three days of information sharing to sharpen our technical skills. It's a privilege to see so many people here and to identify some goals we have in common!

Take a look at the conference program. What a collection of timely topics and a gathering of resource professionals! We have participants from federal, state and local governments, private industry, and from Canada.

This is wonderful! This is evidence of the cooperative context within which we work. We have a lot in common as we manage Alaska's natural resources. Our job titles, our employers, and our fields of expertise are varied, yet we share a common goal in providing good stewardship for natural resources.

We are often referred to as "managers" or "specialists" in our various fields of hydrology, fish and wildlife management, timber management, land management planning, and soil science. Yet, we are more than "managers." "Managers" conduct, direct, govern, regulate, guide, and lead. Yes, we do that. Yet as importantly, we have the additional charge of "stewardship."

Webster defines a "steward" as one called to exercise responsible care over possessions entrusted to him, for example, time, talent, or treasure entrusted to his care. "Stewardship" is the administration of the office of steward. Stewardship is also defined as sharing systematically and proportionately one's time, talent, and material possessions for the benefit of all mankind. **For the benefit of all mankind...things entrusted to one's care...that is the concept!** This is what we, in this room today, are about.

I am pleased the Alaska Region of the Forest Service is hosting this conference on the stewardship of soil, air, and water resources. Beginning with the Organic Act of June 4, 1897, the Forest Service has been charged with the protection and maintenance of watershed values. We have a strong tradition of working cooperatively with private and state land owners and regulatory agencies. We are proud of our charge for stewardship of the lands in the National Forest System, and of our leadership in the professional stewardship of the soil, water, and air resources in Alaska.

Our mission in the Forest Service is not a simple one. Under the Multiple-Use Sustained-Yield Act of 1960 we must make decisions within a political and economic context to provide the best net balance for the public good. There are additional "givens" we must follow: the provisions of the National Forest Management Act, the Alaska National Interest Lands Conservation Act (ANILCA) and the long-term timber sale contracts are only a few examples of further legal requirements.

Part of the Forest Service mission is to maintain or enhance soil productivity and water quality. This requires careful "stewardship" of forest activities, including keeping the soil in place and maintaining natural stream flows.

In terms of water quality, there is no question that timber harvest **may** have a temporary effect on aquatic habitat, but there are many unanswered questions as to the certainty, significance and duration of this effect. Likewise, we have much to learn about the effects of timber management on soils and hence long-term productivity.

Good stewardship requires us to be concerned about many things besides resource use. These include the public's increased interest in water quality, regulation and control of non-point source pollution, and costs. To meet these concerns we need to work together; to collaborate in making wise use of our **human** resources to get the most from our various limited budgets.

Good stewardship involves improving our management practices and processes by monitoring implementation of plans and achieving effective solutions. We expect our best management practices (or BMPs) to control non-point pollution sources. Then we must monitor and evaluate our practices to assure they are working well, that they are the "best", or make them better.

As we go about our stewardship role, we should be thinking in terms of the ecology of the whole riparian zone, using watershed concepts to focus broadly on ecosystems or landscape rather than on trees, water, and fish separately.

Good stewardship means concern for the long-term benefits. Not simply **if** there will be an effect on plant communities, habitat, soil productivity or water quality, but **whether** there will be a significant effect and for how long?

Compromise is part of life. The question is not **whether** compromise is acceptable, but **where** and **when** these necessary compromises are unwise and **unacceptable.** What are the specific limits and conditions of the trade-off? What is appropriate to the situation and the specific site? We must ask ourselves how we can protect the MOST watershed values, not acres, not trees, but **total** overall value. This is the old "extensive" vs. "intensive" management dilemma in a new form.

New thinking raises new questions. What are the "cumulative" effects of activities in watersheds? Is this the same as the so-called "domino effect?" How should an agency treat cumulative effects from prior activities on federal, state, or private lands in the same watershed?

Today's technology may help answer some of these questions. The Forest Service has invested in a system to record and store earth science data. The Geographical Information System, (GIS), contains soil inventory and plant community classifications as **basic** data, which along with timber type maps is used in land management planning. The Forest Service now has this information stored for most Forests or Areas except for classified Wilderness areas and National Monuments.

**Together,** we need to determine how this data base and other scientific methodology can best be used on federal, state, and private lands.

**Together,** we need to define our mutual long-term interests. Land management and regulatory agencies with interests in watershed management ought to join together, as partners, in defining these mutual long-term interests.

**Together!** That means work together, work side by side, and collaboration toward our common goal of stewardship of Alaska's great watershed resources.

Today is the first day of Spring; the first day in the beginning of new relationships, and the dawning of a new emphasis on the stewardship of land and water resources.

# Habitat Management: Some Drainage-wide Considerations

*R.D. Reed*

*Alaska Department of Fish and Game, Juneau, AK*

*Abstract*. Watershed planning is critical for adequate protection of fish and wildlife habitat during timber harvesting. Two types of planning are commonly used. watershed-level and stand-level. Both provide unique opportunities for the land manager. Watershed-level provides the greatest flexiblity for retention of large areas thus providing options for protection of species sensitive to human disturbance or requiring large home ranges. Stand-level planning is site-specific, labor intensive and offers probably the best opportunity to intergrate timber harvest and fish and wildlife habitat protection in those areas where timber harvest will occur.

Today I will touch on two approaches to habitat management and discuss the merits of each from the department's perspective. Timber harvest without watershed planning can be likened to building a house room by room without benefit of plans for the entire structure. Both can be accomplished, but the results will probably be far from satisfactory.

To adequately plan for timber retention which will provide the optimum in fish and wildlife habitat, we need to evaluate the watershed in its entirety and adequately understand the fish and wildlife habitat requirements.

Failure to do so can result in (1) foreclosure of future options, (2) retention of lower quality habitat, and (3) increased costs.

## Discussion

Over the years, the department has approached land planning at two levels. The first is watershed-level planning and the second is stand-level planning within a watershed. Although they can be used together, often times they are considered separately and both proved certain opportunities.

*Watershed-level planning*

In watershed-level planning, the whole watershed is treated as a unit when evaluating its fish and wildlife values and and then compared to other watersheds. The objective is to retain one or more watersheds in an unaltered state, while conducting more intensive harvest operations in other watershed. In some cases this is the only positive way to ensure protection of fish and wildlife habitat. This is especially true when the aim is to maintain the variety of habitat types that are commonly associated with old-growth stands.

An example of this type of planning can be found in the Land Use Designations or LUDs employed in the existing Tongass Land Management Plan. Under that plan, allocations decisions were made on the watershed level. The LUD I and II categories preclude timber harvesting operations while LUD III and IV areas allow varying levels of harvest. When using this approach we concentrate on the broader context of valuable fish and wildlife habitat, and usually are evaluating from an island or region-wide perspective.

Watershed planning is often the only viable option for providing for primitive recreation, or protection of wildlife species with large home ranges such as brown bear or those that are very sensitive to development activities such as mountain goats. In addition, although the department has a good understanding of habitat requirements of certain species such as Sitka black-tailed deer, little is known regarding the habitat needs of many of the species found in southeast Alaska. In the absence of detailed knowledge, watershed planning can be a good option for protection of "functional" habitat systems such as those which allow deer to move from alpine areas to lowland high-volume old growth as the snow conditions require.

Second, as more and more of the existing logging road systems are inter-connected, human access will significantly increase. Protection of whole watershed may very well be the only system capable of providing the long term habitat needs of certain wildlife species. In addition, watershed-level retention may also provide the bast protection from habitat loss due to windthrow.

From a fisheries perspective watershed planning has advantages although perhaps not to the same magnitude as for wildlife. It is generally accepted that timber harvest in a watershed will somewhat impact the fishery resources even though harvesting does not occur adjacent to streams. Activities such as road building and stream crossings can and do impact fishery habitat to some degree, although impacts can be mitigated by proper streamside management. In relation to public participation, watershed-level planning provides an easy means for the general public to track retention areas through the various planning processes.

Finally, it must be realized that when we suggest that "more intensive harvest should be conducted in a given watershed", we are **not** suggesting the watershed harvest techniques that were common in the 1950s and early 1960s where virtually all economical timber was removed from the valley, including that along streams and other sensitive areas. Rather we envision a situation where adequate riparian timber is permanently retained to provide fishery habitat protection and hydrological stability to watercourses. We do see it however as a single entry process which may extend over several years, thus eliminating the cost of moving the camp and constructing new timber harvest related facilities in other areas. We also assume less retention for wildlife needs, with the riparian areas providing the bulk of the wildlife habitat that will remain upon completion of the harvest operations. This process can, however, produce opportunity for intensive second-growth management such as thinning projects.

*Stand-level Planning*

The more site-specific stand-level planning evaluates the types, amount, and location of needed retention areas within a given watershed. The goal is to provide enough retention to insure proper fishery habitat protection and hydrological stability, as well as protection of wildlife habitat, while providing for timber harvest within a watershed.

Where timber harvest will occur, stand-level planning provides the best opportunities to integrate fish and wildlife habitat protection with timber harvesting. Usually in a watershed there are numerous patches, sometimes significant, of old-growth timber that are not harvested for economic or technical reasons. If the location and size of these areas are determined on a watershed basis, options for improving their wildlife habitat value may be possible. For example, with such unharvestable areas known in advance it could be possible to plan travel corridors between them and retained riparian areas with a minimal loss of economical timber volume. Thereby, improving the overall wildlife habitat with a minimum economic impact. Another option could be to buffer "core" old growth stands with areas of extended rotation. If however, harvest proceeds without planning, such options might be lost and the unharvestable timber left may provide little if any value for wildlife habitat.

Examples of such low quality habitat are the residual isolated stands that are often left above clear-cut areas. Such stands provide poor wildlife habitat since there is no protected access to lower elevations. From a wildlife perspective it would be more beneficial to harvest such areas thereby allowing for a corresponding increased retention in stands of higher habitat value.

Stand-level planning can accomplish much. For instance, riparian areas can be established to protect fishery habitat and stream integrity. These in-turn can be linked to high value winter habitat with carefully planned travel corridors. In addition, the best use can be made of the stands which are uneconomical to harvest. Options such as harvesting one side of a watershed and leaving the other can also be explored.

One of the major drawbacks of stand-level planning however is the significant staff that is required to effectively implement it. Another is that with multiple entries into a watershed, retention areas are often difficult to track, and in some cases maintain due to windthrow problems. Finally, stand-level planning can sometimes result in problems associated with prey/predator relationships. During severe winters prey species can be forced into the limited retention areas and thus be very vulnerable to predators.

## Conclusion

In reviewing recent Forest Service planning activities it is evident that both types of planning that I have discussed are routinely used. One recommendation I can offer is that the Forest Service be sure the general public is aware of and involved in the planning that is already occurring. As to which process the department favors, the answer would have to be "both", although due to our limited planning staff intensive stand-level planning is not always possible.

In summary, a major issue in Southeast Alaska is that the same high volume old-growth forest ecosystem that is so important to fish and wildlife resources is also the most economically viable timber to harvest. We consequently believe that trade-offs between resource values are unavoidable.

Although those trade-offs may be unavoidable, perhaps with the proper combination of watershed and stand-level planning we can reduce their severity.

# Water Quality Issues on Private and State Lands

*J. McAllister*

*Alaska Department of Natural Resources, Juneau, AK*

Good morning ladies and gentlemen, and thank you for this opportunity to talk to you this morning about the relationship of water quality and forest practices on state and private forest lands in Alaska. First, I want to discuss briefly our own Forest Practices Act revision process - why we are doing it, where we are in the process, and most importantly, where do we expect to go from here.

Why did we embark on a review of the Forest Practices Act?

I'm sure you've all heard the expression: "If it ain't broke, don't fix it!" I know there were some, particularly a few loggers and others in the timber industry, who felt that this expression pretty much summed up their feelings on revising the Forest Practices Act. However, in response to criticisms of the act, and to improve resource protection while retaining a viable timber industry, the Governor directed the Department of Natural /resources, Fish and Game, and Environmental Conservation to conduct a public review of the act and make recommendations for improvement in the act, its regulations, and implementations.

To achieve an objective and balanced review, the review process included representatives of timber land owners, state agencies, and users of public resources affected by forest practices. A steering committee, composed of these various groups, was the body responsible for guiding the review process and recommending any changes. All of the parties agreed to negotiate in good faith and to try and reach an agreement by consensus.

Secondly, where are we in the current Forest Practices Review?

Well, as a result of six days of continuous negotiations and three and half months of intensive effort, a draft "Agreement-in-Principle" was reached on March 1st with some significant proposed changes to the act and its regulations. After Steering Committee review of the "Agreement-in-Principle" the agreement will be submitted, as I speak, to each steering committee members' parent organization for ratification or rejection. If approved by consensus, legislation implementing this agreement will be submitted during the 1989 session. Once legislation is passed, DNR, working with the Departments of Fish and Game and Environmental Conservation, and steering committee members, will draft and promulgate regulations consistent with this agreement. Policy changes that do not require legislation or regulation, such as education and training, will be implemented by the appropriate department.

Lastly, what changes do we expect to see as a result of this review process?

Let me first highlight some of the more significant changes to the Alaska Forest Practices Act that have been proposed:

-DNR'S enforcement capabilities are greatly strengthened, existing civil penalties will be streamlined and criminal penalties added.

-We will have a better hearing and appeals process.

-We will have a single state enforcement strategy for forest practices violations.

-DNR'S Forest planning process is greatly enhanced with new statutory and regulatory emphasis on wildlife habitat, scenic quality and other non-timber issues, in addition to more public participation in forest planning.

-And there is even proposed language encouraging private land owners to enter into cooperative wildlife agreements with the Department of Fish and Game.

But the two pivotal issues at the heart of the Forest Practices review were:

(1) Riparian management and

(2) an enhanced notification of operation process

both of which directly relate to the protection of water quality.

The riparian management agreement proposes a streamside management program for the protection of fisheries and water quality. Within the enhanced notification process, and in concert with the development of new regulations, there will be a system of enforceable standards that will satisfy the requirements of the Forest Practices Act and, hopefully, DEC's nonpoint source pollution control program.

You may ask yourself (as a few haggard participants in our forest practices review probably did during some of those late night meetings!): "why do we even have forest practices acts?"

Well, browse through any state's forest practices act and I think you'll find common intent language in all of them, such as ". . .the forest resources are among the most valuable of all resources of the state. . ."; ". . .a

viable forest industry warrants continuing recognition and support. . ."; ". . .ensure continual supplies of renewable resources. . ."; ". . .encourage and ensure the regrowth, reforestation of commercial tree species. . ."

Finally, you will find two important water quality statements - principal parts of any forest practices - and these are ". . .the protection of soils, and water quality and quantity. . ."

And, secondly, there's generally a statement regarding compliance with federal and state law with respect to control of nonpoint sources of water pollution from forest practices.

Section 208 of the Clean Water Act of 1977 was the impetus for Alaska's own Forest Practices Act of 1978. The current act has sections that encourage the Commissioner of DNR to develop regulations in conjunction with the Department of Environmental Conservation for control of nonpoint source pollution as a part of a state program.

Section 319 of the Clean Water Act, as amended, further directs DEC, among other things, to identify nonpoint sources, identify affected waters, and directs the state to describe nonpoint source control programs and strategies. I don't really want to get into all the in's and out's of the 319 program at this time because Dave Sturdevant, our next speaker, will be getting into this topic.

However, I mention it because it is important to note that the 319 Nonpoint Source Management Program directs states to identify [and I quote] ". . . programs including, as appropriate, . . .regulatory programs . . .to achieve implementation of best management practices." [end quote] As many of you probably know, best management practices, known as BMPs, are simply, according to the EPA definition: ". . . methods, measures, or practices to prevent or reduce water pollution. . .[and] usually. . .are applied as a system of practices rather than a single practice."

For instance, the rules and regulations of the forest practices acts of the various Pacific Northwest state's, **are**, in fact, their "BMPs." It is interesting to note though, that of the Pacific Northwest states, including Idaho, Alaska is the only state that has yet to have its forest practices regulations certified as a means to control nonpoint source pollution and for meeting water quality standards.

There are two particular types of BMPs, sometimes known as "process" or design BMPs, and "standard" or performance BMPs.

A process BMP does not document specific actions to be taken, instead this type of BMP establishes a procedure to be followed which will result in the formulation of tailor-made methods and techniques for nonpoint pollution control.

On the other hand, some typical examples of standard BMPs are sets of state forest practices rules and regulations. These commonly consist of a list preventive preventive methods and measured from which the timber operator selects the practices to apply. Flexibility of the practices and fitting to site suitability are accomplished by having more than one fixed measure or practice to select from to accomplish protection. The focus is on the end result.

But how effective will our proposed BMPS be? Will we craft a system of practices that do, in fact, prevent or reduce nonpoint source pollution from timber practices on forest lands? The answer is simple: without effective monitoring we can't answer these questions.

Other states have wrestled with these same questions and, interestingly, Idaho is presently attempting to implement an "Antidegradation Policy" for the protection of water quality. There is a significant feature within that policy, namely: a strong statement of need for the development and coordination of a statewide water quality monitoring program.

In a previous life more than fifteen years ago, I was involved in the opening up of a remote major drainage in the Oregon Cascades. I was a logging engineer for Weyerhauser Company at the time. An item was installed before any logging took place. In this river was placed an automatic water sampling collection system. Even in the early 1970's the importance of water quality monitoring was recognized as being important to protect the interests of downstream users as well as the company.

Well, presently, it's not feasible to measure water quality protection results in Alaskan streams. Agencies lack resources to gain the pertinent data. Hence, the effectiveness of BMPs is really based on the best professional judgement of the forestry, fisheries, and DEC staff.

Best professional judgement in water quality matters is not an exact science, it is rather a function of interest, training, perspective, and state-of-the-art water quality protection methods. For these reasons professional foresters and fisheries biologists may mot agree on the impact timber harvesting may have on a given waterbody, if any at all. And, of course, what is considered proper today, may be deemed ruinous tomorrow.

Even when BMPs are agreed upon by the regulatory agency and by the industry involved, they may be difficult to enforce and it is necessary to establish their effectiveness. When markets for timber products are depressed, operators are less than enthusiastic about implementing costly water quality protective measures.

It is recognized that Best Management Practices are the primary mechanism to enable the achievement of water quality standards, aand the process should include:

(1) The design of BMPs based on site-specific conditions, technical, economic, and institutional feasibility, and this water quality standards of those waters potentially impacted.

(2) A monitoring system to ensure that practices are correctly designed and applied.

(3) To determine:

a) the effectiveness of practices in meeting water quality standards, and

b) the appropriateness of water quality criteria in reasonably assuring protection of beneficial uses, and lastly,

(4) the adjustment of BMPs when it is found that water quality standards are not being protected to a desired level and/or a possible adjustment of water quality standards.

Furthermore, we must have ongoing information and education programs directed towards logging operators and, finally, the establishment of an enforcement presence to ensure compliance with forest practices and water quality standards.

What does it all mean? It means that, if properly developed, the Forest Practices Act and, more specifically, its regulations, can serve as a certified nonpoint source pollution control program for Alaska. It means that, for Alaska to have effective BMPs, effective in both an economic and environmental sense, they must be updated and backed by a sound monitoring program. I encourage you to take an active role in their creation. Thank you.

# The State of Alaska
# Nonpoint Source Pollution Control Program

*D. Sturdevant*

*Alaska Department of Environmental Conservation, Juneau, AK*

In this talk, I would like to describe for you the State's efforts to comply with Section 319 of the CWA, which requires each state to develop a Nonpoint Source Pollution Assessment Report, and a Management Program to control Nonpoint Source Pollution.

Section 319 was added to the CWA in February 1987, along with other important new programs. However, concern for Nonpoint Source Pollution goes back more than a decade. Many of you recall the nonpoint source planning program under Section 208 of the Clean Water Act, passed in 1977. Under Section 208, the Department of Environmental Conservation prepared analytical reports and guidelines for pollution control on a number of subjects, including timber harvest, waste oil disposal, transportation, onsite wastewater disposal, and dairy waste disposal. Some aspects of these plans have found their way into implementation. The 208 program nationally was not judged a great success, primarily because of the lack of funding to carry planning into implementation. New direction has now been provided nationally through Section 319.

Before we examine the new program, I will offer a definition of Nonpoint Source Pollution. First of all, **Point Sources** are discharges of wastewater from a pipe, ditch or other discrete conveyance. **Point Sources** usually are regulated by a State wastewater discharge permit or a federal NPDES permit. Typical **Point Sources** include sewage treatment plants, pulp mills, refineries, and seafood processors. In Alaska, log transfer facilities and placer mining settling ponds also are permitted as **Point Sources.**

In contrast, **Nonpoint Sources** are widespread, diffused pollutant sources, that traditionally have included such things as agriculture, urban runoff, and yes, silviculture. **Nonpoint Source Pollution** is controlled by such things as resource planning, procedural mechanisms, performance standards, best management practices, public education and water quality monitoring, all of which the Forest Service is well familiar with.

Section 319 is a response to national concern over Nonpoint Source Pollution. It has been estimated that 73% of the oxygen demand, 84% of nutrients, 98% of bacteria counts, and 99% of suspended solids in the nations waters come from Nonpoint Sources.

In developing Section 319, the Congress added a 7th national policy to the preamble of the CWA, which reads: **It is the national policy that programs for the control of nonpoint sources of pollution by developed and implemented in an expeditious manner so as to enable the goals of this act to be met through the control of both point and nonpoint sources of pollution.**

Section 319 establishes three phases of a national Nonpoint Source Pollution control program.

> First, each state is required to prepare an **Assessment Report**, which identifies all waterbodies affected by Nonpoint Source Pollution, and describes categories of Nonpoint Source Pollution.
>
> In the second phase, each state is required to prepare a **Management Program** which describes programs and activities that the state will implement to reduce Nonpoint Source Pollution over a four-year period. The MS must be approved by the Governor, and reviewed and approved by EPS. We refer to the Management Program as the Nonpoint Source Pollution Control Strategy, or Management Strategy.
>
> The third phase is implementation of the approved MS over the four-period.

I'll explain these further in a moment.

Now, implementation costs money, and lack of money for implementation was the primary reason for lack of success in 208. In Section 319, Congress authorized approximately $100 million per year for four years. Half of the money has to be divided equally among the states. Section 319 grants must be matched by State funding at the level of 40%. As you know, authorizing funding and appropriating funding are two different animals. This year and last year, no money was appropriated by Congress for 319. Many people regard future funding as pessimistic. However, it should be noted that without the Management Strategies completed, there essentially has been nothing to fund to date.

Let me move on to the specific of the Alaskan program. We prepared a draft AR last December using

input from a Working Group of State and Federal agencies. The Assessment entered a public review period which ran from January 6 to February 6 of this year. Because of a high level of public interest and concern, particularly among affected industries, the comment period was extended thru March 24, next Friday. We have already received a substantial number of comments, and we will be revising the Assessment to incorporate these comments.

The AR does two things. First, it lists all waterbodiess we identified as being **Impaired, threatened,** or **unimpaired**. Impaired means there is evidence that the waterbody is violating, or recently has violated, the States WQS. Threatened means that existing or anticipated activities can reasonably be expected to cause future problems with WQS. Some waterbodies also are classed a Unimpaired.

The second thing the AR does, is to describe in general narrative terms the impact of water quality of eight categories of activity: **timber harvest, placer mining, oil and gas development, agriculture, urban development, onsite sewage disposal, fuel and chemical storage, and harbors and boating wastes**. I hope each of you will agree that there are Nonpoint Source problems to be concerned about in each of these categories.

Now, we have been criticized for a couple of procedural things. One is the definitions used for determining **impaired** and **threatened** waterbodies. Another is reliance on observations of professional agency staff to make these determinations. Actually, about 25% of waterbodies rely on some degree of hard data, and the rest are based on Best Professional Judgement of field staff. The staff involved were mainly from the Department of Environmental Conservation, Fish and Game, and Natural Resources; the Forest Service, Fish and Wildlife Service, NOAA, BLM, and National Park Service.

I will say two things about Impaired and Threatened water bodies. First, these terms are given to us by EPA as part of the national program. Second, these terms represent what we must get at -- that is, **identifying waterbodies which are presently affected, and waterbodies which are likely to become affected.** On the matter of Best Professional Judgement, there is simply no alternative, because of the sparse data available in Alaska. In the absence of cold, hard date,the judgement of professional agency staff is defensible in the eyes of the CWA.

Please note also that we used a conservative approach in labeling waterbodies. That is, in cases of uncertainty, we used Threatened instead of Impaired, or Unimpaired instead of Threatened.

Concern also has been expressed that we overlooknatural pollution in the AR, particularly the high sediment load in glacial streams and major rivers. Our position is simple -- we accept natural conditions as the baseline. The AWQS apply to pollution caused by humans.

Again, because of the high degree of public interest in the Assessment Report, Commissioner Kelso has instructed us to fully consider concerns expressed by agencies, industry, and the public, in revising the draft report. We expect the final Assessment Report sometime this spring.

Let's turn to the Manageament Sstrategy -- What is the nature of the Strategy? The heart of the Strategy is a set of recommendations or proposals for each Nonpoint Source Pollution category, expressing **what needs to done to begin to control Nonpoint Source Pollution**. The recommendations may include such things as public education, technical assistance, Best Management Practices, cooperative agreements, research, monitoring, and funding. It is important to recognize that the recommendations will **describe activities that need to be done.** The actual products will be developed during the implementation phase over a four-year period.

The recommendations will be assigned priorities, and will be linked to anticipated funding. The Management Strategy contains other important materials as well, all requirements of Section 319

-It will present summaries of **existing** Nonpoint Source Pollution control programs.

-It will briefly describe existing Best Management Practices.

-It will contain a section on federal consistency, which identifies federal programs which the State will review to assure consistency with the approved Management Strategy.

We commenced work on the Management Strategy in January. We are including the active participation of a **full range of concerned industry and public interest groups as well as State and federal agencies and municipalities** in developing the Strategy. These groups were invited to attend orientation meetings in February to explain the objectives and the process. We formed eight Working Groups, one for each category in the Assessment Report. We are actively working with these groups to develop the required material, and have asked participants to deliver input to us by March 31.

At the same time, concern has been expressed that the Assessment and Strategy phases are overlapping because of extension of the public comment period on the Assessment. We plan to focus on completing

the Assessment Report before preparing the draft Management Strategy.

The draft Management Strategy will then go through extensive public review. Because of high public interest, we will proceed with caution and attempt to ensure communication with all concerned parties. We expect to receive vigorous public scrutiny from all sides throughout this process .

As a note in regard to Timber Harvest, the Management Strategy will fully embrace the revised State Forest Practices Program being developed by the public Forest Practices Steering Committee.

Finally, I want to emphasize that we view this program as a very constructive opportunity to examine Nonpoint Source Pollution in Alaska, and to develop cooperative measures for protection of water quality in the state. We look forward to constructive interactions with agencies, cities, interest groups, and the public in completing this important program.

# Biodiversity and Watershed Management

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**Introduction**

*Arlene Doyle:*

Good afternoon and welcome to our panel on biodiversity and watershed management. Concern for biological diversity is increasing, yet we have limited understanding about what biological diversity is, how we should measure it, and how we should manage for it. One of the problems of defining biological diversity is that it occurs on many different scales. These scales include diversity within a species, community, ecosystem, watershed, or region. Diversity also occurs on different levels, such as within-stand diversity, between-stand diversity, and landscape diversity. Simply defined, biological diversity is the variety of life occurring at these different levels and scales. Interest in biodiversity stems in part from the increasing rate of species extinctions on a global scale. There is also concern that reduction in genetic variability within a species may result in reduced genetic fitness. There is national concern about the trade-offs associated with the conversion of forests from older, more heterogeneous forest stands to younger, even-aged stands. The effect of fragmenting old-growth forests into smaller, isolated patches could result in isolated wildlife populations more susceptible to local extinctions.

To maintain or enhance biological diversity is a challenge to us as representatives of federal, state, and private agencies, and as individuals. The National Forest Management Act of 1976 directs the Forest Service to "provide for diversity of plant and animal communities...in order to meet overall multiple-use objectives." The Forest Service is further directed to "maintain viable populations of exiting native and desired non-native vertebrate species in the planning area. For planning purposes, a viable population shall be regarded as one which has the estimated numbers and distribution of reproductive individuals to insure its continued existence is well distributed in the planning area...habitat must be provided to support, at least, a minimum number of reproductive individuals and that habitat must be well distributed so that those individuals can interact with others in the planning area."

There is currently a national emphasis on developing a strategy for maintaining or enhancing biological diversity. We need to develop inventories to evaluate current, historic, and projected levels of biodiversity. We also need to develop strategies for the recovery of endangered species, protection of plant and animal communities, and management of the landscape. To be effective, these strategies should be incorporated into our overall programs within state, federal, and private organizations, and need to incorporate our continuing need for natural resources. We can help by developing an understanding of biodiversity and developing a strategy for biodiversity which we incorporate into each of our programs.

Towards that end we have several panel members to discuss biological diversity and watershed management. Paul Alaback is with the Forest Sciences Laboratory in Juneau and will discuss biodiversity as it relates to ecosystems. Matt Kirchhoff from Alaska Department of Fish and Game will be the next presenter and will discuss the relationship of biodiversity to species management, especially for wildlife and fisheries. Jere Christner, with the U.S. Forest Service in Sitka, will present the hydrologic implications of biodiversity and Ron Wolfe, a forester with Klukwan Forest Products, will discuss timber management implications of biodiversity.

I would like to begin with Paul Alaback. Paul is currently a Research Ecologist with the Forest Sciences Lab. He has a B.S. in Botany and Forestry from University of Washington and a Ph.D. in Forest Ecology from Oregon State University. He has been studying the ecology of rain forests in southeast Alaska since 1976 specifically focusing on plant succession following logging as it relates to wildlife habitat values. He has just returned from Chile and Argentina where he studied issues of biological diversity and global warming in the rain forests in that area.

## Diversity of Ecosystems

*Paul Alaback:*

Diversity is a really interesting concept in science. Everybody has a strong feeling about it, yet all of our definitions are very different. For many decades the definition and importance of biodiversity has been quite elusive. For a long time ecologists debated the relationship between diversity and stability. It was thought that stability was the rationale for diversity, i.e., if you had a more diverse system, then it was expected to be more resilient to change. However, the tropics are highly disturbed systems and are among the most diverse, whereas some of the least disturbed systems are not particularly diverse. Diversity is important in part because it is part of the heritage of the evolution of the earth. Extinction rates are well documented as increasing exponentially over time so this is not only a local problem, but a regional and even global problem.

What is biodiversity? Quite simply it is the variability among living organisms and the ecological complexes in which they occur. What has complicated the definition of biodiversity is that it occurs at many different levels and is defined differently at each of these levels.

The most obvious level is the species level. If there are species extinctions, then biodiversity is clearly reduced. Even if there are no species extinctions, we need to at least be concerned about population genetics. There are fine-tuned mechanisms for development of local populations such as their ability to adapt to microsites over time and their ability to adapt to environmental changes. The elimination of these local populations results in reduced biodiversity.

The ecosystem level is one of the most important levels of biodiversity. This is one of the key areas I wanted to talk about, but it is difficult to work with, because everyone has a different definition of what an ecosystem is, and depending on what your goals are, you might come up with a completely different classification system to work with. I think it is important to think about functional processes. The watershed level is a macro-scale, in which many animal species may be functioning. An example of the regional level might be the number of species of plants and animals in coastal Alaska, or on the Tongass National Forest. The strategy for biodiversity should be multi-faceted, dealing with different levels simultaneously. Some reasons for being concerned about biodiversity include that biodiversity is a very important element in global climatic change. If you have many different species with different adaptations perhaps that ecosystem could buffer global climatic change more effectively than an ecosystem with only a few common species (which have to rapidly change to adapt to a completely different environment).

Some say we're doing a grand experiment on the earth right now by modifying land-use practices very rapidly, while we still don't know very much about the majority of the species that inhabit the earth. A conservative philosophy would be to conserve some of these ecosystems, assuming that by so doing we'll be preserving some species about which we don't know very much. A rare species might seem unimportant, but there is a long history of instances in which relatively rare species had extremely important chemicals or enabled us to learn scientific concepts that had many broad applications. So it's a valuable heritage that we don't want to lose.

The elements of diversity are usually divided into three basic levels: alpha, beta, and gamma diversity. Alpha diversity is the number of species that occur in the level you're working at. For example, in a forest in southeast Alaska, alpha diversity would be the number of plant and animal species that occur in that one ecosystem. Beta diversity is the number of habitats that occur in a watershed, for example. If you have a watershed of many different plant communities in different successional stages it would have a high beta diversity as opposed to a watershed that has one age class of one plant community type. Gamma diversity is the integration of these two diversity levels, i.e., the number of species and the number of ecosystem types in an area. The other important feature is species distributions. Most species groups display a log-normal distribution, that is, a few species are very abundant and many species are relatively rare. So you could potentially increase diversity by decreasing the common species and increasing the rare species. It's usually not something you can do, but conceptually you might think of it that way.

When we were on a task force dealing with diversity in the revision of the Tongass National Forest Land Management Plan we discussed how diversity had traditionally been dealt with. The diversity mandate in the Forest Land Management Act of 1976 came about primarily because of concern about type conversion, i.e., taking a native forest type and converting it into a very different forest type, especially an exotic species. We tried to look at functional units. For example, there might be 10 different 10 year-age classes in a managed forest and one age class in an unmanaged forest, e.g., old-growth. If your emphasis is wildlife it would be better to functionally group stands. For example, old-growth has a number of species in different distribution patterns. A mature second-growth forest might have a greater abundance of mosses and some ferns, things like that.

An early stage of second-growth, that is a recent clearcut, might have a great diversity. So you might use these three functional stages rather than arbitrary ten year age classes to effectively deal with how different management alternatives affect the diversity of the forest, especially for wildlife.

Some people think disturbance is important to maintain diversity. The kind of disturbance is, of course, very important. We think that old-growth forests tend to be more diverse than second-growth forests because they are continually disturbed and the disturbances are all slightly different, creating different kinds of openings, different lighting, etc. It creates a more diverse environment than say, an even-aged stand where the light penetration may be more uniform.

I would like to sum up with a thought on how we can address diversity in a general way. The Nature Conservancy has a phrase: "last of the least, best of the rest". I believe an important strategy of preserving diversity might be to try to preserve regional diversity. There are a few rare species and rare ecosystems in southeast Alaska. We could define the region into general climatic zones, and then, through research natural areas and retention management schemes, make sure we have represented these different species and ecosystems. At the ecosystem level, we could start identifying the rare ecosystems in a watershed for example. By increasing the relative abundance of those types you're going to be conserving diversity.

We have different land ownerships in southeast Alaska. We need to see how this whole system fits together in terms of National Park Service, National Forest Service, native corporations, and private land ownership. The animals don't know political boundaries. How do these things fit together? I think that's what's so useful about this emphasis on biodiversity is that it's a synthetic concept. It brings a lot of information together.

*Arlene Doyle:*

The following speaker is Matt Kirchhoff. He is a wildlife biologist in the Division of Wildlife Conservation with the Alaska Department of Fish and Game. He is the project leader for deer research in southeast Alaska for the division and has studied wildlife habitat relationships in southeast Alaska since 1979. Today he is going to speak with us about biodiversity as it relates to management of wildlife.

*Matt Kirchhoff:*

We've traditionally assumed that within a watershed achieving maximum habitat diversity will result in maximum wildlife or species diversity. In general I think it is true that if you take a watershed that's completely forested in old-growth and break that up into a mosaic of old-growth and second-growth forest of various ages then we will have more species than the old-growth forest did originally. However, we need to focus on our objective. Is that the kind of diversity we want to manage for? Managing for the maximum number of species of a local area or in a watershed may not be an appropriate management objective. In fact, it may operate at the expense of species or communities that we are most concerned with and that are most deserving of our protection.

We can probably assume that wildlife species diversity is correlated with habitat diversity. We don't need to know all of the species that are out there, we just have to look at habitat diversity, whether it's diversity within a particular habitat type or diversity of different habitats in a watershed. The more diversity we have in habitat, the more wildlife species diversity we can expect. Furthermore, high species diversity assumes more than the simple presence of a species, it assumes that species exist in sufficient numbers to maintain a viable population over a long period of time.

There are several different ways that we can measure or manage for diversity: the first, alpha diversity, is the number of species in a single habitat within a particular community. For example, old-growth forest is a very diverse habitat with many associated wildlife species. It is structurally diverse with many niches for different species. Beta diversity is the number of species found between habitats and communities. So again, on a watershed scale, if you've got old-growth and second-growth and clearcuts, you've got high beta diversity and you've got more species at that level. The third level is the number of species over a large geographic area and is sometimes called gamma diversity. We don't have a clear consensus on what the geographic scale of gamma diversity is. I view it as a multiple watershed level, for example biodiversity on large islands such as Kuiu or Kupreanof Island.

How does clearcut logging affect diversity at each of these scales? Alpha, or within habitat diversity is almost always reduced when we log an old-growth forest. Although there may be a slight increase in the shrub/sapling stage of the regenerating stand, that fairly rapidly gives way to an even-aged second-growth condition which is characteristically low in diversity and persists for a long period of time. Alpha diversity in the past has rarely been considered in forest planning.

Diversity across the broader landscape, or gamma diversity, is also rarely considered in forest planning. In very large geographic scales, for example over the whole Tongass National Forest, it is unlikely that we would see any extinctions of species. But as we move

that geographic scale down from the Tongass-wide level to a series of smaller areas, perhaps several watersheds, I think we do in fact run the risk of eliminating some species.

Beta diversity, sometimes called between-habitat diversity, is the habitat diversity for which managers most often strive. For this level of biodiversity, timber harvesting creates new habitats, taking old-growth forest and creating clearcuts, second-growth, roads, dumps, campsites, a whole variety of small habitats which, because they are new, attract new species. These new species may not necessarily be new to the region or to the Tongass National Forest, but they are new to that local area and at that scale, and in that sense, they are increasing diversity.

What should be our goal? Emphasis on sheer numbers of species and habitats can be dangerous. Do we need to provide habitat for widespread or opportunistic species that do well in managed forests? Would we meet our conservation objectives by providing habitat for porcupines and red squirrels and starlings in managed habitats if the trade-off is to eliminate habitat for brown bears?

We don't need to manage the local landscape for the maximum number of species, we need to manage it for those species that are most at risk. What species are at risk? As suggested, the law of limits indicates that rare species are obviously at risk. Not only those that are rare in a regional sense across the Tongass National Forest, but those that might be rare on a smaller geographic scale, for example, Peregrine falcons and ospreys. Deer on Kuiu Island are very rare. You might want to give special consideration and priority to managing for the perpetuation of these species in those areas.

Secondly, species with large area requirements are at risk. The brown bear is an excellent example. On northeast Chichagof Island, between Point Frederick and Tenakee Inlet, roads and logging activity are expected to bring every bear in that area into contact with roads and people in the course of it's lifetime. With an estimated total population in that area of 115 to 125 bears, a sustainable harvest of six or seven bears per year would allow continuation of that population. Currently that harvest level is exceeded by the defense of life and property and illegal kill alone. So, in the absence of some change there, for example some kind of management that would prevent people from using roads, it looks like the long-term viability of bears in that geographic area or at that scale is threatened.

Thirdly, species that are adversely affected by edge may be at risk. This is somewhat surprising, since we typically associate edge as a positive benefit for biodiversity and it may in fact increase diversity, but it specifically increases certain species that are attracted to edge, usually at the expense of other species that do not do very well along edges. Most of the literature in this area deals with birds and the fact that forest interior birds suffer higher nest predation rates and have lower clutch sizes along edges. So, if we're interested in preserving those wildlife species, we need to be concerned about creating too much edge, for example by clearcutting.

And finally, wilderness species - animals that are sensitive to human activity or related development - are at risk. Alaska is fortunate to have a number of wilderness species. Some of the species that fall into this category include the brown bear, mountain goat, marten, and wolf.

Where should we be headed in terms of managing the landscape for diversity? I think we need to acknowledge that the natural ecosystem complex is the optimum condition and we should be striving to preserve that type of characteristic diversity. If the areas we preserve are large enough we can be comfortable that we are perpetuating the functional processes of the way these different habitat patches interact.

Secondly, we should emphasize protection of rare and valuable habitats. High-volume old growth forests and riparian habitats have been disproportionately impacted by logging over the last 30 years. These habitats are rare. They are essential to many important species and they are at high risk for logging. A moratorium on logging in these habitat types would be prudent from a biodiversity standpoint.

Thirdly, large reserves should generally be favored over small reserves. Debate continues over whether one large reserve or several smaller ones of equivalent total area would best meet the goals of maintaining biological diversity. But looking at those species that are most at risk, it seems that conservation efforts should focus on the larger preserves. We do not need to view these options as exclusive, but should at least provide some large reserves for species that require them.

To summarize, species composition and abundance, not simply the number of species, should be our main concern. Rare species should be favored over wide-spread species. Rare and valuable habitats should be protected to the maximum extent possible. The presettlement, or pristine landscape, is the optimum condition. And finally, large, natural areas offer the best prospects for the long-term maintenance of biological diversity.

*Arlene Doyle:*

The next speaker is Jere Christner. Jere has been in southeast Alaska since 1985 and is presently staff

officer for the Chatham Area for fish, wildlife, watershed, and ecology. He was previously on the Willamette National Forest in western Oregon for seven years. He has worked in Colorado, Nevada, and eastern California. He has an M.S. in hydrology and a B.S. in forest management and will discuss the hydrologic implications of biodiversity.

### Hydrologic Implications of Biodiversity

*Jere Christner:*

People who have been working with and studying watershed management over the years have been involved in biodiversity, or vegetative diversity, and probably didn't know it. Watersheds are a product of the influence of climate upon geology and landform as modified by vegetation and change over time, due to erosion, climatic variation, and vegetative changes. To people in watershed management, the diversity concept is really not meaningful unless there is a change in biodiversity such that a change in watershed response occurs as well.

I would like to discuss some of the factors that changes in biodiversity can affect and I'll give you just a few on-site and off-site examples. A change in vegetative diversity (e.g., vegetative species, age or structure, plant distribution, percent cover, etc.) can affect a change in hydrologic and watershed factors. For example, average wind velocity in an open, recently clearcut area is higher than in a mature-forest stand.

Another example is the storage of snow under different forest conditions. In a stand of large trees, snow is deposited and held in the canopy on large branches because there is enough strength in the branches and enough leaf area to support the snow. Trees in a younger stand of second-growth don't hold snow on the branches because they don't have the strength to support the snow. In a shelterwood with a few large trees, there is not enough density to hold much snow.

Transpiration and insulation from radiation can be influenced by a change in plant species diversity. A good example is that water temperature in the summer can increase if streamside shade is eliminated. Conversely, in the winter, water temperature may decrease if there isn't insulative cover by vegetation over a stream. Rooting influences slope stability and moisture depletion. Nutrients in the stream are affected by plant species composition, including presence of alder which fixes nitrogen.

Another type of hydrologic impact of biodiversity concerns peak or flood flows. This can be illustrated by stream flows at Salmon Creek and the North Fork drainage in the Cascades. In that area of the country, when trees reach about 25 years old they tend to modify the wind movement and can start to modify snow accumulation and storage. In early years, in the North Fork drainage there was some railroad logging. In 1935, about 10 percent of the North Fork drainage was logged, whereas about two percent of the Salmon Creek drainage was logged. Over time more logging occurred in North Fork and gradually shifted into Salmon Creek. As logging increased in Salmon Creek relative to the North Fork drainage, peak flows also increased in Salmon Creek relative to the North Fork drainage. What is the consequence of stream flow changes? Peak flows can influence habitat, sediment, general water quality, channel changes, and on-site soil failures. If there is a change in how moisture is delivered to the soil, in terms of timing or the amount delivered within a given time, it could also influence landslides. Diversity influences can be subtle. Assume that we build a section of road in a drainage and that road intercepts some water and routes it to a stream. That stream may adjust to a small increase in stream flow. If we build another section of road, more water is collected and routed to the stream and the channel may again adjust to that increased flow. If an additional section of road is built and even more water is routed into the stream, this time it may not adjust. Significant change may occur, such as widening of the channel or substantial erosion, as a result of cumulative effects.

There are essentially three kinds of cumulative effects. The first is additive, in which effects simply add up, e.g., sediment from some tributary streams combine and run off downstream. Secondly, there is the domino effect. For example, a landslide can cause stream blockage, resulting in undercutting a stream bank, which in turn releases sediment, which flows downstream and covers some salmon redds. An example of a synergistic, or feedback system, would be if there is a blowdown and some wood falls into a stream, stores some sand and gravel behind a log, vegetation gets established on that sandbar and a new stream bank develops.

To summarize, biodiversity is important in terms of watershed management if changes in biological diversity influence how the watershed functions, including stream flow, subsurface water flow, extreme events, soil stability, and snow accumulation.

*Arlene Doyle:*

Ron Wolfe is a forester with Klukwan Forest Products in Juneau. He came to southeast Alaska from New Mexico. He arrived in 1982 in a position with the Tlingit-Haida Central Council as a professional forester. He has a bachelor's in forest resource management from the

University of Montana and will discuss the timber management implications of biodiversity.

### Timber Management Implications of Biodiversity

*Ron Wolfe:*

The industry's response, brought about by the current political climate on the Tongass National Forest, is a defensive posture, one that the industry feels is at the essence of our survival. We wouldn't be in a position to comment extensively on biodiversity until we have an answer as to what the impact of this philosophy would be on the current annual allowable cut, and what the impact would be on our operating costs. We feel that the timber on the Tongass National Forest is going to be more and more valuable as other forests become somewhat reduced. Because it is a fixed and finite quantity, we see it increasing in value over time. That's important to note because during the most recent five to eight years, the industry has been in a severe slump. We feel there is potential to actually increase the annual allowable cut on the Tongass National Forest above the 450 million board feet per year, if there is a will to do so.

One of the concerns that came out of the negotiations on the Forest Practices Act was the need to have a real yardstick that tells us how we are doing. We believe we've been trying to protect resources for some time without any feedback on how well we've done in protecting those resources. We want to get the biggest bang for our buck of protection for a public resource. We could justify, for instance, protecting salmon streams because of the high cash value that's associated with the salmon fisheries. We want the protection to be meaningful and effective. We have less inclination to protect other resources on private lands that have less cash value than anadromous fish have.

Those are the philosophies, as they occur to me, on private lands and I recognize and understand that on public lands, such as National Forest lands, it is clearly different, but from a timber management perspective, I think the same philosophy must extend to public forest lands. Otherwise, the public as the owner is losing out on revenues that might be derived from the development of resources in a manner that would protect public resources, wildlife populations, etc. Naturally, as an industry that wants to participate in the development of public forest lands, we would view it as losing the chance of doing business.

Consequently, when I hear things such as that we should call for a moratorium on timber cutting in the riparian zones and old-growth forests, it's something of great concern. Before we could subscribe to that we would have to have a significant reason. I certainly acknowledge that the reason may be there and I'm simply not aware of it. Forest management should be driven by the protection of a resource that makes sense. Management of wildlife populations for management's sake is something I have difficulty with. And diversity in species, etc. is something that I as a forester can understand the logic to, but would accept only after a bit more work, before it would be a persuasive argument to me.

*Arlene Doyle:*

I'd like to open it up for questions and will begin with a question myself. Ron had many good points and we need to keep in mind one of the points he brought up, that is that government agencies such as the Forest Service may not have the flexibility that the private timber industry would have in terms of managing for biological diversity. The Forest Service is directed to maintain diversity so the question is not if we're going to maintain it but how, and to what degree. It behooves us to work towards solutions together, recognizing the need to use natural resources while maintaining biological diversity. Jerry Franklin and others have been talking a great deal about a concept called "sloppy clearcuts", and I thought that Paul Alaback or Matt Kirchhoff could explain what that means and discuss it as a potential solution.

*Paul Alaback:*

In some cases we're talking about doing things differently, but not necessarily resulting in greater expense or a reduction in the allowable cut. Sloppy clearcuts are an excellent example of this. Traditional forest management practices in recent years have been to cut down all the trees, even unmerchantable trees. Sometimes there's a specific reason for that, such as for mistletoe infestation or for improving regeneration, etc. However, it has been suggested by Jerry Franklin and others that one of the basic problems with even-aged forests is the environment is so uniform that the ecosystem responds very quickly and produces a very uniform forest. One way to make the forest less uniform is if some of the small intermediate sized trees that were originally suppressed are left standing as a future source of snags or to provide partial shade and less disturbed understory populations. Some of the leave trees could be material that would be unmerchantable. Leaving this material creates a more heterogeneous environment and increases the diversity of the forest at minimal cost. In fact, the cost might even be lower in some of these instances than traditional forest management practices.

Some of the most diverse ecosystems are those that have different kinds of disturbances, usually light, but frequent disturbances, so if we want to make a more

diverse ecosystem, changes in harvesting philosophy such as the sloppy clearcuts would be good. Other regions are now beginning to talk about uneven-aged silviculture, and that would be another instance where enhancing biodiversity wouldn't neccessarily reduce resource outputs.

*John Standerwick:*

This is the National Forest Management Act and I think it's important, at least for us folks with the Forest Service, to go back to this occasion and see what it says. In relation to biodiversity it says the Forest Service will "provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet overall multiple-use objectives, and within the multiple-use objectives of a land management plan adopted pursuant to this section, provide, where appropriate, to the degree practicable, for steps to be taken to preserve the diversity of tree species similar to that existing in the region controlled by the plan."

Matt, I'm not sure you meant what you said about the moratorium on high-volume old-growth. That wouldn't be acceptable within the constraints of our multiple use objectives. We could take a portion of the high-volume old-growth and set it aside as a research natural area, but we are constrained to manage for all the resources that are on the national forest. I think that consideration for economics alone would be as contrary to those objectives as simply setting aside all of our high-volume old-growth. Somewhere in between is where we have to be.

*Matt Kirchhoff:*

As far as the moratorium is concerned, I think that would be a prudent policy to follow from the standpoint of maintaining or optimizing biodiversity on the forest. I agree it's a balancing act, and unfortunately it's a little late in the game to start balancing it out. I think we've had a long history on the Tongass National Forest of not having adequate balance or adequate concern for some of these rare habitat types. All I'm suggesting is that, at a minimum, when we go into a new watershed or new drainage we don't disproportionately impact those rare habitats, we don't schedule timber cutting of more of the volume class six and seven than exists in the natural watershed. Recognizing the economic importance of those types of stands and their importance to the timber industry, I realize it's unrealistic to expect that those are going to be permanently protected, but I think we need to give more emphasis than we have in the past in protecting those types.

*Mark Orme:*

Matt made a statement that pristine is best and is most diverse. I think our viewpoint of pristine is really shortsighted. I've worked professionally for 20 or 30 years, and I'm sure I don't understand even if I worked in one area for that entire time all of the ecological processes that go on. I saw 500,000 acres of old-growth lodgepole which a lot of conservationists were saying should be preserved, completely recycled by the pine bark beetle and so we couldn't preserve it even if we wanted to in the pristine conditions. I'm not so sure that we understand everything to say that pristine is always best.

My other comment is that I think part of biological diversity is the harvest of species. We know that harvesting game animals changes age structures, sex ratios, and those sorts of things that affect diversity. If we're concerned about rare species, why isn't there more concern for controlling trapping the lynx in southeast Alaska. I think we need to take a broader look at diversity than just vegetation management.

*Matt Kirchhoff:*

I view pristine as meaning not altered by man. We're not trying to freeze succession, prevent natural landslides, prevent insect infestations, and so forth, but as Paul touched on in his talk, there's a fairly recent recognition that man, from a global perspective, is rapidly changing the landscape and we don't understand the implications of those changes. The subject of biodiversity suggests that some of those changes may have adverse impacts on very specific species. When I say that the optimum landscape is the pristine landscape, I mean the natural landscape, including some second-growth, some landslides, etc.

In terms of the importance of other agency actions for maintaining diversity, I agree completely. I think Alaska Department of Fish and Game has to be more aware of the implications of its game management policies, such as the effect of seasons and bag limits on marten in heavily-roaded areas on Prince of Wales Island and northeast Chichagof, and brown bears on northeast Chichagof. These are things we're just beginning to recognize ourselves. It's a fairly new area, and I don't mean to point the finger at any one agency when I make these recommendations. Biodiversity is something we should all be aware of and all agencies should work together towards.

*Audience Speaker:*

In these rare habitat types that are eliminated, there are forces that create openings, and setback succession, and create diversity. Would it be possible to

manage timber in such a way that you simulate those conditions by making unit size a lot smaller, and planning cuts so you end up with different age-structure and size-classes next to each other.

*Paul Alaback:*

I think it depends on what your pristine condition is. If we were dealing with lodgepole pine in the Rockies it would be fairly easy to simulate that situation - a catastrophic disturbance followed by a period of maturation. If the system we are trying to emulate is an old-growth forest, where trees are falling over continuously from non-catastrophic wind-throw events, then the best simulation might be an uneven-aged management strategy, although everything's a matter of degree. Clearcut units of a certain size might begin to emulate small gap openings and there's a lot of discussion about this now. The riparian zone might be the most obvious place to experiment with uneven-aged management strategy to emulate more of the natural disturbance regime.

*Ron Wolfe:*

From a forest economics standpoint, I believe that uneven-aged forest management with a large-scale application, such as on the Tongass National Forest, could conceivably drive our operating costs up to where I doubt we could operate on a broad scale operation on the Tongass today. I would like to respond to the possibilities of uneven-aged management in riparian zones. I'm not sure we're talking about the same thing. When you suggest uneven-aged forest management, what that translates to me would be that within the riparian management zone, I would have the opportunity to go in on a selective basis and remove a few of the individual trees. We are very interested in exploring that in our discussions with the conservationists and the Habitat Division of the Alaska Department of Fish and Game.

I do feel that that the logging technologies we have today and use in southeast Alaska, should be kept in mind. That presents operational difficulties that can be overcome if, in the marking of the trees to cut, we keep in mind how they're going to have to be removed. What drives us are the high-value trees. I believe Mr. Harris this morning talked about individual trees that, to us, can net or at least gross $10,000. We're very interested in getting every one of those out we possibly can. At the same time, the costs associated with riparian zones are very significant - millions of dollars. So, any way we can take some of the sting out of that we're very interested in talking to people about it.

*Audience Speaker:*

My understanding of uneven-aged management is that it creates a balance of age classes, and in that sense, I suppose, you're creating high-value trees for the future. From a timber industry standpoint, are we in the situation in southeast Alaska where we need a certain age class to be economical to log? Do smaller trees have enough value to be cost effective to log?

*Ron Wolfe:*

The industry in southeast Alaska, in my opinion, has not developed to the point where we can handle small logs. We're interested in cost analysis that address the costs associated with handling these small logs. There is disagreement among the industry on what the correct approach to this analysis is. It differs to the extent that on private forest land we do not have the same utilization standards that the Forest Service has - that small logs present a significant enough problem to us that we view our costs differently.

The opportunity that I do see for approaching the harvest of all age classes within a specified zone such as the riparian management zone is with high-lead logging - the predominant logging system in southeast - if you've got a nice tree and there are a number of trees in front of it that are of different age classes, then simply fall all of them so you have a clean shot to the landing. That would be one way, in a sense, that uneven-aged management could be accomplished.

*Paul Alaback:*

There are a lot of different ways that uneven-aged management has been done. One of the typical ways, such as the old European model, would not necessarily involve cutting trees of all ages simultaneously, but rather using a diameter limit and pulling out trees that are above a certain diameter limit periodically. And when the second age-class reaches that diameter limit, then going after those.

*John Standerwick:*

Our experience with uneven-aged management in the region is limited. During the war, there was a spruce program in southeast Alaska that took a number of spruce trees out and that is about the only uneven-aged program that existed other than simply taking the bigger spruce trees in the early days of logging. So we need to be pretty careful. We're considering some of this in the revision of the Tongass Land Management Plan, and we've done some uneven-aged management in some areas. We did it along Pavlof River. When conditions are right, you can do it.

*Ron Wolfe:*

I doubt that selective harvest will ever be a major technique for economic logging here in southeast. There has been a long history of high grading along the coastline where individual trees are hand-logged and jacked out of the woods. Those trees are the $10,000 trees that Rick Harris is talking about, are very valuable, and you can spend all day getting one of those trees out of the woods. If you're going to try to feed two pulp mills and supply 450 million board feet per year, there's no way you're going to do that with selective logging. I think everyone recognizes that. Perhaps in specific situations along important riparian corridors, where you've got a road nearby and don't have to snake a log out through a hundred yards of residual stand, there are some possibilities for doing something to maintain biodiversity. But as a practical alternative to clearcutting on the Tongass National Forest, given the demands of the wood products industry, I don't think it's realistic.

*Audience Speaker:*

Those sorts of comments were heard from southern Oregon 10-15 years ago. The same sorts of things were considered economically unfeasible, but on the Siskiyou National Forest and a lot of other areas, as emphasis changed in the programs, we've seen good changes in the way we do business. The same is true with tractor-logging in that area. That was considered the only economical means to log, and now less than one percent of the area is tractor-logged.

*Audience Speaker:*

If we do have a number of trees that are worth the kind of money we're discussing - $10,000 per tree or so - would helicopters be an option to selectively remove trees in riparian zones?

*Ron Wolfe:*

The industry - my company for instance - is currently developing helicopter logging plans. We see that as a technique that is very expensive and limited in its application for harvesting trees.

*Audience Speaker:*

I'm having trouble with this topic of biodiversity. I get the feeling that our concern for biodiversity probably stems from the tropical forest, and applying it to southeast Alaska is like mixing apples and oranges. I'm sure it's a concern, but I think that if we're concerned about below-cost timber sales, we're really going to be concerned about below-cost diversity enhancement. The rationale for biodiversity seems to be that someday we may find a rare species that's valuable to us, but it sounds like if we did find that rare and valuable species, you wouldn't let us manage it.

*Matt Kirchhoff:*

Some of the old-growth forests of the Pacific Northwest, for example, are very similar to the forests we have up here and we have seen a loss of a number of important species including brown bear, timber wolf, and mountain lions as those forests have become increasingly fragmented and converted from old-growth status to second-growth status, so there is a clear record in this country of losing species as we fragment the landscape. I agree that the tropical rain forest is much more critical in terms of the number of species at risk and the rate at which it's being deforested and converted into agricultural land. So, we do have to recognize the differences.

*Audience Speaker:*

Is balloon logging feasible in southeast Alaska?

*John Standerwick:*

Balloon logging, when it operated, was very successful because it could bring in more volume quicker than the normal high-lead logging system. But the problem we didn't recognize when we introduced the balloon logging system into southeast Alaska, was that we didn't understand how critical the wind problems were. The balloon is what they call an onion-shaped balloon, and when you get over 25 MPH wind it pitches and loses stability, resulting in the balloon and logs going every-which-way. When it was operating it was fine, but we had to tie it down during periods of 25 MPH winds or better, and there are too many of those periods. It's very expensive equipment and the logistics were a nightmare.

*Audience Speaker:*

It seems to me I'm hearing, from Ron and a couple of people in the audience, that one of the main arguments against preserving large areas of old-growth is that there is so little knowledge out there about what biodiversity really means in southeast Alaska. When there's a lack of knowledge it may be wisest to err on the side of preserving that situation until you have some answers because you'll always have the opportunity to log it in the future.

*Ron Wolfe:*

I would have to ask what we are hoping to benefit by setting aside these areas, especially large tracts of old-growth. We view it as being very costly. Until we can entertain that dialog, I'm not advocating either way.

*Paul Alaback:*

Some of these questions get almost philosophical, such as, "Is it alright to wipe out a species or not?" I prefer to avoid that level. One application of being somewhat conservative might be to look at your rarest things as your top priority. I don't think it's realistic to talk about biodiversity as being a primary impetus for having very large tracts of reserves. I think that's unlikely. Probably what we're realistically talking about is doing that which isn't being done with other objectives. For example, you might have a few rare species that occur in some fairly small areas. With the focus of biodiversity I think that would have a relatively high priority. We should probably try to conserve examples of that which we originally had. Everything obviously has to be balanced, I think biodiversity might be a way of judging the relative value of protecting different areas.

*John Standerwick:*

Most people would tell you we've already erred on the side of the conservative. We do have some pretty large wilderness areas. We should recognize them for their value as far as conserving some of those systems.

*Matt Kirchhoff:*

I think if we stepped back and looked at it from a national perspective or from even a global perspective, we'd have a much better appreciation of how little old-growth there is left in the world. In North America there's probably less than five percent of the original extent of old-growth. Most of that exists today in southeast Alaska. Admiralty Island is a large wilderness area in southeast Alaska, but compared to the old growth that's been logged on Vancouver Island and coastal British Columbia in the last 20 years, it's a very small and insignificant amount of old-growth. I think from a wildlife conservation standpoint, there's a good basis for erring on the side of conservation until we know what the effects are going to be on individual species.

*Ron Wolfe:*

Matt, can you give me some ballpark estimate as to the time you feel the scientific community would need to answer these questions?

*Matt Kirchhoff:*

I'd rather not approach it on a species-by-species basis, since I think we're as concerned about preserving ecosystems as we are concerned about preserving individual species. If we continue logging at the pace we're logging, and just worry about it on a species-by-species basis, with the millions of species we've got out there, we're going to be out of luck. We'll be out of old-growth before we even scratch the surface.

*Audience Speaker:*

How do small village communities in southeast, such as Klawock, Kake, or Hoonah, make out in terms of loss or benefit in biodiversity as a result of logging in those areas? And what does that tell us about the non-dollar values associated with biodiversity?

*Matt Kirchhoff:*

I'm not personally very familiar with the situation around Klawock. I've looked at some timber type maps and I know how much of that area has been logged and I suspect that as a result of that scale of logging there will be decreased deer populations. How important that is to the residents of Klawock, as opposed to the economic benefit they get from the jobs and timber resources, is a personal decision they have to make. But certainly there is going to be a trade-off in terms of reduced habitat diversity and reduced species diversity in those areas.

*Arlene Doyle:*

I want to thank our panel members and audience for the discussion of biological diversity as it relates to landscape and ecosystem management, fish and wildlife species, hydrologic implications, and timber management implications. We have exciting years ahead as we seek to understand biological diversity and to implement strategies of biodiversity into our programs.

# Moving Towards Ecosystem Management: The Forest Service Ecology Program in Alaska

*J. R. Martin*

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***Abstract.*** The Alaska Region of the Forest Service began a new program: The Alaska Region Ecology Program. Program emphasis is on providing ecological approaches to managing landscapes including the development of ecosystem classification systems, the development of management interpretations of these systems, providing personnel training on use of these systems, and providing technical assistance on key conservation issues. Ecologists in this program are expected to be generalists and integrators of both people and ecosystem data; hence, often will function as facilitators. They can be expected to provide technical assistance to a wide variety of disciplines and resource data towards the goal of achieving ecosystem management. Current work emphasis of 4 ecologists in the Region is on development of plant association classification systems. Over 50 different forest plant associations have been described and draft classifications are available for northern, central, and southern portions of southeastern Alaska. Field work in southcentral Alaska on the Chugach National Forest began in 1987 on the "Big Islands" in Prince William Sound and in the white spruce zone on the Kenai Peninsula. Draft classifications for these areas will be available in 1 - 2 years. Final publications of the forest plant association classifications for the Tongass National Forest will be available in the near future. Two ecologists in this program are working on advanced degrees in cooperative studies with the University of Washington and the U.S. Forest Service Forest Sciences Laboratory in Juneau, Alaska. These studies will provide needed management information on regeneration and succession of riparian ecosystems and on the definition and maintenance of old growth forest. Beyond completion of the current classifications, focus will be on refinement and maintenance of classifications and management interpretations, development of non-forest plant association classifications, and technical assistance on conservation issues.

There has never been a time when so many people have become so aware of the interconnectedness of their lives to the environment. This awareness is shown in numerous laws (USDA Forest Service, 1983), federal policies, and the great diversity of natural resource disciplines in public agencies. In 3 decades, we have moved from an agricultural to a petroleum based, high tech society. At the global and local scale, species and environments are changing at a rapid rate. Global awareness of these changes and the ecological implications to our future existence is great. At the National Forest level, this awareness is shown by concerns about biological diversity, old growth forests, riparian and wetland habitats, and global climatic change; to name a few. These conservation issues are creating new and exciting challenges for public and private resource managers. Solutions are rooted in our understanding of ecological principles, in our willingness to listen and utilize current information, and in our ablility to provide leadership in often controversial areas.

Recently the Alaska Region of the U.S. Forest Service began a new program: The Alaska Region Ecology Program. The decision by the Regional Forester to initiate this program is in response to greater public interest in natural resource conservation issues. It is fitting that the first public announcement of this program be made at this Watershed 89 conference, because soil scientists and hydrologists in this region have played a key role in the development of this program. Watershed specialists have historically been leaders in promoting ecosystem management through the development of inventory methods for predicting soil and water productivity and management response.

The objectives of this paper, in addition to providing information about this new program in the Alaska Region are to:

1) Define the role of the ecologist, in particular how they can help forest managers do their jobs more effectively,
2) Provide an overview of the current ecology program organization and projects in the Region,
3) To encourage the continued support of watershed personnel in the development of the ecology program.

### What is Ecosystem Management

An ecosystem is defined as a complete system of interacting organisms considered together with their environment[1]. This definition is very similar to Tansley's

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[1]USDA Forest Service 1983. Ecosystem classification, interpretation and application *in* Forest Service Manual, (FSM 2060).

(1935) original concept, where it was defined as any complex of living organisms with their environment that we isolate mentally for purposes of study. It was further defined as the fundamental unit in ecology and as existing in both space and time. Barbour and others (1980) consider it to be the sum of the plant community, animal community, and environment in a particular region or habitat. Ecosystem management is an extension of the ecosystem concept and is defined (USDA-Forest Service, 1983b) as the use of ecosystem concepts to predict effects of management actions on ecosystems and to guide management planning and actions.

While the ecosystem concept is widely discussed and emphasized in natural resource management and research, the concept has been (Tansley, 1935) and continues to be (O'Neil et al., 1986) a difficult one to define. This has been in part due to the many different perspectives of ecologists. These perspectives have largely been a result of differing spatial or temporal scales ecologists have emphasized in their work. Ecologists focused on plant succession tend to emphasize temporal scales, while those concerned with current distributions of species or communities emphasize spatial boundaries in defining and studying ecosystems. Traditionally, both approaches have focused on simple interactions (reductionism) rather than on the more complex multivariate interactions of systems. These simple interactions are then combined in often complex, difficult to test, ecosystem models. Reductionism has also led to very narrow definition of ecosystems and their components (soil taxonomy, plant community classifications). While it is neccessary to simplify the system, current thinking is causing ecologists to put these narrowly defined components back together into larger pieces needed to answer questions at different scales. This is shown by the newly emerging disciplines of conservation biology (Soule, 1980) and landscape ecology (Forman, 1986) where the need to look at the "bigger picture" or to take a global viewpoint (Wilcove, 1988) in our study and management of ecosystems is emphasized.

Increasing importance is being placed on using ecosystem concepts in the management of natural resources. This presents a challenge to managers since many of our models about ecosystem functioning are currently developing and are untested. None the less, setting attainable ecosystem management objectives and evaluation of the effectiveness of current programs in meeting those objectives is of particular interest to managers. Taking the view that ecosystem management is in its developmental stages is important when evaluating program status and setting long term goals. Many of us working in natural resource management can visualize a time (maybe 20 years) when all the needed spatial and temporal scale ecosystem data is appropriately linked, tested and available in a "user friendly" database; hence the title for this paper, "Moving Towards Ecosystem Management". Such a database would allow managers to readily answer questions about biological productivity and ecosystem response to manipulation, at the appropriate scale and time. While it is valuable to consider this long term vision, ecological concepts need to be a part of ongoing management. When the silviculturist considers water-nutrient relations in reforestation as it relates to seedling survival, ecosystem concepts are being used. When the influence of surrounding human activities has on the successful management of a stand are considered, ecosystem concepts are again being applied, but at a different scale. Management of the coarse woody debris component of a stand for long term productivity and floodplain stability in the silviculture prescription, again is another example of using ecosystem concepts in management.

### Role of Ecologist in the Alaska Region

An ecologist's primary responsibility in the Alaska Region is to provide a focus and emphasis on the development of ecological approaches to management of the Forest Service lands. This requires ecologists to be generalists and integrators. Ecologists are expected to work towards integration of natural resource data and people of varied disciplines. Integration of data involves providing common linkages to the land which are ecologically derived, easy to use, and useable by all natural resource disciplines. Effective application of ecological concepts in management requires strong interpersonal communication skills in addition to technical skills. Ecologists should have no strong ownership in any one functional discipline, but ownership in many; hence a generalist. Ecologists should be expected to integrate silviculture, forestry, biology, hydrology, soil science and other specialists in achieving ecosystem management objectives.

Investment in developing and integrating ecological appoaches to management is a long term committment. For example, typical plant association classification systems for a national forest will take from 6 to 8 years to complete[1]. Coupling the plant association classifica-

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[1]Volland, L. A. 1988. Pacific Northwest ecology program summary. Unpublished Forest Service report on file, Portland, OR.

tions with mapping systems and other ecosystem components (soils, channel types) can extend this time if done independent of other resources. This time has been shortened on the Tongass N.F. by developing the classifications in conjunction with soil mapping and inventory. Some program benefits can be expected in 2 to 3 years if time is taken to communicate findings as the program develops. Benefits of employing ecologists to assist in key conservation issues can be realized almost immediately. However, as the information requests become specific to a land area rather than process related, ecologists will be less helpful until adequate time has been spent in an area and the classifications are in a useable form.

Ecologists are not new to the research branch of the Forest Service but are relatively new to the National Forest System (NFS). Ecologists were first hired in the NFS in the late 1960's and the early 1970's. These ecologists worked principally on development of habitat type or plant association classification systems (Hall 1973, Pfister 1977). Since that time, all Regions of the NFS have hired ecologists to work on ecosystem classification. Today, there are approximately 40-45 ecologists working on ecosystem classification throughout the NFS.

The 4 primary responsibilities of the ecologists in the Alaska Region are:

1) Ecosystem classification
2) Facilitate development of management interpretations
3) Technology Transfer
4) Bridging gaps between management and research

### Ecosystem Classification

Different parts of a landscape have different soils, vegetation, geomorphology, hydrologic, and climatic characteristics. These must be classified in order to communicate more effectively about resource capabilities and opportunities. Communication may involve simple or complex data comparisons, mapping for planning, development of management recommendations about a particular type, or for a focus for establishment of long term monitoring plans. Ecosystem classification systems are essential to the land manager for establishing these common communication linkages between the land and its associated resources. They are the foundation to the achievement of the long term goal of ecosystem management.

While classification systems are a human artifact, the principal criteria used to classify ecosystems must be natural and reflect ecological processes. This approach ensures that resulting classifications are effective for describing and predicting ecosystem function and change. Additionally, terminology used in a classification needs to be easily understood and useable by varied natural resource disciplines. This is essential to ensuring that the classification will be used in resource management decisions.

The classification should be capable of blending into an ecosystem hierarchy (O'Neill et al. 1986). These hierarchies vary from broad to narrow and are designed to address different questions at different spatial and temporal scales. An example of a possible ecosystem hierarchy in Southeast Alaska from broad to specific could be: **Biogeoclimatic zone** (Pojar et al. 1987), **Admiralty Island, Streamside Riparian, Sitka spruce (*Picea sitchensis*) series on alluvium, Sitka spruce/ devil's club (*Oplopanax horridum*)-salmonberry (*Rubus spectabilis*) plant association, Sitka spruce/ devil's club-salmonberry-sandy soil ecological type.** While broader levels of this hierarchy exist, Admiralty Island is used to illustrate a relatively closed, broad level ecosystem. The riparian ecosystem is a narrower subset defined by general geomorphic and vegetative features in close proximity to water. A further subset of this ecosystem (forest series) includes all the plant associations defined by the dominance of Sitka spruce on alluvial soils. The riparian ecological type (plant association and soils or other environmental feature) is the finest level of organization in this example. This hierarchy reflects natural landscape boundaries and provides a basis for developing broad level management plans (Forest Plans) or site specific project level plans. If used at the broad level planning phase, it provides a natural or ecological linkage to the site specific needs of the project. In other words, prescriptions written in the Forest Plan for the riparian ecosystem can be refined at the project level using the riparian ecological types.

### Management Interpretations

Once the classifications have been completed, management interpretations are developed. This is an interdisciplinary process which involves the ecologists principally as facilitators. Ecologists will provide the framework through the classification and a summary of the ecological processes and characteristics about each level of the classification. Biologists, silviculturists, and other specialists should provide their past experience and data pertinent to the classification. For example, silviculturalists have had difficulties regenerating Sitka spruce riparian sites in southeast Alaska. The data and knowledge acquired by the silviculturists in SE Alaska can be pooled according to ecological type and

provide the basis for developing the initial interpretations. Depending on need, these may be refined with more detailed data collection by either ecologists, research or the particular discipline needing the data.

### Technology Transfer

Transfer of information about the ecosystem classification system, ecological processes effecting the forest, the response of ecosystems to change and about emerging conservation issues is a large part of the responsibility of the ecologist. This information will be distributed through publications, training sessions, seminars, and day to day interactions with specialists at all levels of the Forest Service. Successful implementation of ecosystem management through a progressive program of information transfer is essential.

### Bridging Gaps Between Management and Research

Ecologists serve as a principal laison between research within and outside the Forest Service. Ecologists should not replace the current responsibility of research in bridging gaps, but supplement this effort through close cooperation and coordination. Providing classification systems, better defining research needs of management, supporting research, and facilitating cooperative projects between various organizations are a few examples of how ecologists can help bridge gaps.

### Overview of Current Program Organization and Projects

The Director of Fish and Wildlife in the Regional Office, Juneau is responsible for providing program direction. The Forest Supervisor on the Chatham Area, Tongass National Forest is responsible for ensuring that this direction is carried out through the Ecology Program Coordinator. Each area/forest level ecologists is responsible to their respective Forest Supervisors for implementing their ecology programs.

Currently, there is 1 ecologist working at the Regional level, 4 in southeastern Alaska, and 1 in southcentral Alaska. Three ecologists have been working full time on the development of forest plant association classifications and 2 ecologists are working on advanced degrees on special projects in cooperation with the Pacific Northwest Station-Forestry Sciences Laboratory, Juneau and the University of Washington.

Program emphasis in southeastern Alaska has been on completion of plant association classifications and development of management interpretations of plant associations for the revision of the Tongass Forest Plan[1]. The forest plant associations (Martin et al., 1985; DeMeo et al., 1989; Martin, 1989; Pawuk and Kissinger, 1989) are mapped with soils and landforms into ecosystem mapping units (Downs et al., 1984). These units are digitized on 2 inch/mile map base in an ARC/INFO Geographic Information System (Martin 1989). These ecosystem units, together with the stream channel mapping system (Marion and Paustian, 1983), are combined according to the plant association and soils to map riparian areas (West et al., 1989), wetland habitat (DeMeo and Loggy, 1989), old growth types (Martin, 1989), wildlife habitat, and to determine timber suitability.

Ecologists on the Chugach National Forest are developing classifications of the forest plant associations on the islands in Prince William Sound (Borchers et al., 1989) and in the Cooper Landing area on the Kenai Peninsula. The Prince William Sound plant associations will be used initially to identify and describe wildlife habitat and evaluate site productivity and harvest response in silvicultural prescriptions. The Cooper Landing project will focus on identifying plant associations, describing successional plant communities and pathways, and past fire and insect disturbance history. This work will initially be used for predicting vegetation response to prescribed burning of moose habitat and evaluating the best silvicultural treatments of spruce bark infested stands. Draft classifications of these projects are expected in 2 to 3 years.

### A Look to the Future of the Ecology Program

Completion of the classifications of all vegetative communities in the Region will require 10 to 15 years based on current activities and estimates of completion time of similar projects in the western United States. These classifications will require refinement and maintenance over time as management needs become more specific. Development of management interpretations is an ongoing project dependent upon need. The need for solid site productivity estimates, better predictions of vegetation response to change, and understory biomass in old growth types is immediate. Technology

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[1]Barton, M. A. 1985. Forest Service, August 23, memo to Forest Supervisors, Tongass N.F.

transfer through formal and informal training and assistance to specialists of a variety of disciplines will continue to be an essential job. Likewise, working closely with research and management to bride-the-gap between new information and conservation issues will continue.

Emerging emphasis on biological diversity will require ecologists to take on new roles and responsibilities at all levels of the agency. Other issues in conservation biology including old growth forest, riparian management, and global issues to name a few will continue to challenge thinking and actions in natural resource conservation. Ecologists will be needed to keep abreast of these challenges at all levels of the agency.

## Summary

The decision to formally adopt the Alaska Region Ecology program sends an important signal to the public that the Forest Service is serious about conservation of public resources. While there has always been a need for sound ecological information on site productivity and management response, increased public awareness has sparked a need for a stronger emphasis on ecosystem management.

Ecologists are generalists and integrators. They can be expected to work towards integration of natural resource data with people of various disciplines. Integration of data involves providing common linkages to the land which are ecologically derived, easy to use, and useable by all natural resource disciplines. Effective integration requires strong interpersonal communication skills and ownership in all disciplines.

An ecologist's program of work is focused on the development of ecosystem classification systems, management interpretations of these systems, technology transfer and assistance on key conservation issues, and bridging gaps between research and management. There is currently 1 ecologist working at the Regional level, 4 in southeastern Alaska and 1 in southcentral Alaska. Draft classifications are available for southeastern Alaska. Final publications will be available over the next 3 years. Field work on the Chugach National Forest began in 1987 in Prince William Sound and on the Kenai Peninsula. Draft classifications for these areas will be available in 1990. Beyond completion of the existing work, focus will be on refinement of classifications and management interpretations, non-forest classifications, and technical support on conservation issues.

Accomplishment of ecosystem management objectives should be viewed as a challenging journey. This journey will take time to fully realize and will require the participation of all resource disciplines. Accomplishments and rewards will continue as we move towards our eventual goal.

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# Forest Plant Associations of Montague Island, Chugach National Forest: Preliminary Results

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***Abstract.*** Montague Island is the most southerly of three large islands that extend across the south side of Prince William Sound in Alaska. The forest plant associations described in this paper are preliminary results from field data collected in the summer of 1988. Three major series were found on Montague Island - the Sitka spruce series, the mountain hemlock series, and the western hemlock series. The Sitka spruce series occupies beach-front terraces and alluvial bottomlands. Blueberry, devil's club, skunk cabbage, lady fern, oak fern and shield fern are the most common understory species. The lowland rolling hills (elevation <500 feet), raised knolls in muskegs, and steep sideslopes (elevation >500 feet) support the mountain hemlock series. Blueberry and devil's club are the major shrubs, typical of the lowland rolling hills. Raised knolls are typified by copperbush, crowberry, bog blueberry, and deer cabbage. Above 500 feet elevation, copperbush and deer cabbage are replaced by martens cassiope, luetkea, shield fern, and lady fern. The western hemlock series occupies beach-front terraces and lowland rolling hills. Blueberry , rusty menziesii, and devil's club are the dominant shrubs with bunchberry, five-leaf bramble, and twisted stalk in the herb layer. Within these three series 16 associations were recognized. The final product of this work will be a Forest Plant Association Guide for use by managers to better interpret the value of a site with respect to wildlife and fisheries habitat, recreational use, and timber management.

Chugach National Forest contains 5,936,000 acres that stretch from the Chugach State Park near Girdwood and the eastern Kenai Peninsula to beyond the Bering River east of Cordova including Prince William Sound (Figure 1). The growing responsibilities in managing these forest lands have generated numerous questions. How does a manager distinguished between forest types? How will a forest type respond to management? What effect will management have on bio-diversity? How productive are these forest types? To help answer these questions we use the vegetation and soils of a site to indicate potential species composition, response to management, and productivity. A classification of long-term, stable plant communities (or associations), especially when combined with soils information, can be the basis of resources evaluation, project planning, and land management planning (Forest Service 1986).

This study was the first attempt to classify forest lands on the Chugach National Forest based on quantitative data. The objectives were to:

1. Describe forest plant associations and provide a field guide for managers.
2. Describe and recommend management alternatives.
3. Map the relationships between forest plant associations and soil mapping units.

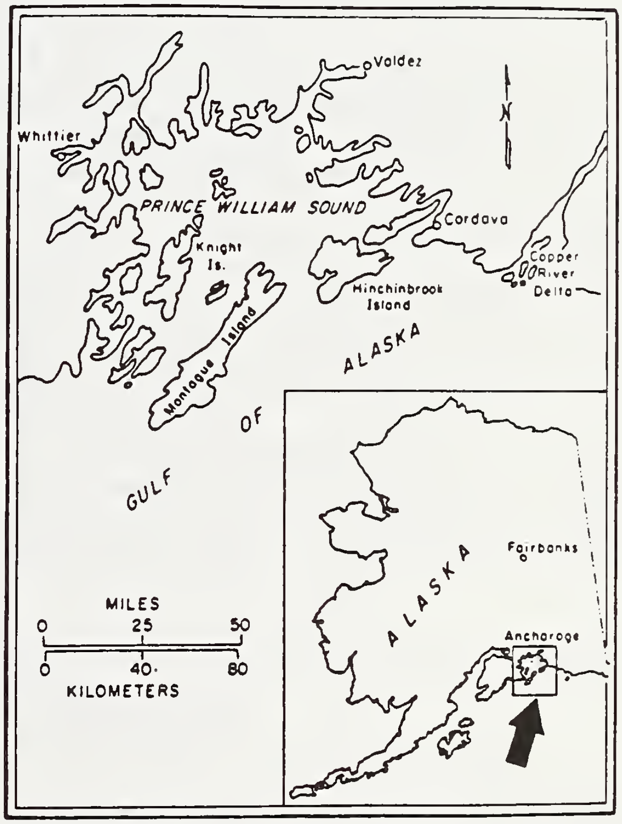


Figure 1. Map of Prince William Sound, AK.

## Methods

*Landform, Climate, and Geology*

Montague Island is the largest outer island of Prince William Sound (Figure 1). The island is 51 miles long by 4 to 12 miles wide with rugged, snow-capped mountains and gentle rolling lowlands with deeply-dissected notches. Precipitation in Prince William Sound ranges from 60 inches to 145 inches per year with a mean annual maximum snowpack of 40 inches. Summer temperatures average around 50°F in the summer and 20°F in the winter months (Cooper 1942). The bedrock of Montague Island is part of the Orca group, which consists of sandstones and siltstones. Unconsolidated Quaternary glacial till veneers the bedrock on low-lying parts of the island, while thick deposits of coarse alluvium line the lower reaches of larger streams. Talus, landslide deposits, and frost rubble commonly conceal bedrock on and at the base of the steeper slopes (Plafker 1967).

*Study Area and Sampling Procedures*

Four study areas were established on Montague Island (Figure 2): 1) Stump Lake, on the outer coast; 2) Rocky Bay, at the northern tip; 3) Port Chalmers, on the inner coast; and, 4) San Juan Bay, on the southwest tip.

Stands were selected prior to on-the-ground investigation using aerial photographs. The following guidelines used for stand selection are identical to the ones used on Tongass National Forest:

1) In order to represent the full range of climax forest vegetation and environmental conditions, stands were selected throughout the landscape.
2) Stands were 1/2 to 1 acre in size. Plots within the stands had a 42 foot radius.
3) Stands were selected if the overstory and understory vegetation appeared homogeneous and in old growth or climax successional stage.
4) Soils, slope, aspect, and microtopography were relatively uniform.

At each fixed plot physical site factors (i.e. landform and aspect) and soil features were noted. Percent cover for all trees, shrubs, graminoid and forb species were estimated. Soil pits were dug and profiles described at plot center. Species, diameter, total height, crown ratio, crown class, tree class and age of all trees were recorded from variable plots established at plot center.

A total of 119 plots were sorted into plant associations using TWINSPAN, a polythetic divisive method of classification that yields a two-way table where species as well as samples are classified (Hill 1979a). DECORANA was used to perform detrended correspondence analysis based on reciprocal averaging (Hill 1979b; Hill and Gauch 1980).

**Figure 2. Montague Island showing locations of the four study sites.**

## Forest Plant Associations

Three major series were found - the Sitka spruce series, the mountain hemlock series, and the western hemlock series. Within these three series 16 forest plant associations were recognized:

Sitka spruce series
1. Sitka spruce/Sitka alder-blueberry
2. Sitka spruce/blueberry
3. Sitka spruce/blueberry-devil's club
4. Sitka spruce/blueberry/skunk cabbage
5. Sitka spruce/Pacific reedgrass
6. Sitka spruce/lady fern

Mountain hemlock series
7. Mountain hemlock/bluebery
8. Mountain hemlock/blueberry-martens cassiope
9. Mountain hemlock/blueberry-devil's club
10. Mountain hemlock/blueberry/skunk cabbage
11. Mountain hemlock/blueberry/deer cabbage/Pacific reedgrass
12. Mountain hemlock/copperbush/crowberry/deer cabbage

Western hemlock series
13. Western hemlock/blueberry
14. Western hemlock/blueberry-devil's club
15. Western hemlock/blueberry/skunk cabbage
16. Western hemlock/blueberry/Pacific reedgrass

The following is a description of vegetation and environmental characteristics for each forest plant association including tables of average percent cover and percent constancy of dominant species. Field guide, management alternatives, and map are not included.

1. *Picea sitchensis/Alnus sinuata-Vaccinium spp*
PISI/ALSI-VACCI
Sitka spruce/Sitka alder-blueberry

Forests are dominated by Sitka spruce (Table 1). Occasionally mountain hemlock are found in the overstory. Sitka spruce comprises most of the conifer seedlings and saplings. A layer of Sitka alder (average height 15 feet), blueberry, and devil's club form a shrub understory. The most common herbaceous species are foamflower, bunchberry, lady fern, oak fern, and shield fern.

These stands occupy active floodplains and alluvial bottomlands at low elevations (0-100 feet) on gentle slopes (5%) with varying aspects (Table 4). However, it is not unusual to find these stands at higher elevations especially with alluvial activity and snow avalanches. Soils are somewhat poorly-drained with a sandy or gravelly surface.

2. *Picea sitchensis/Vaccinium spp*
PISI/VACCI
Sitka spruce/blueberry

This forest plant association is dominated by Sitka spruce with mountain hemlock and western hemlock as major associates (Table 1). Tree reproduction consists of Sitka spruce, mountain hemlock, and western hemlock. Blueberry dominates the shrub layer with minor components of salmonberry, devil's club, and rusty menziesia. Five-leaf bramble dominates the herb layer. Other herbaceous species are bunchberry, twisted stalk, foamflower, and oak fern.

The Sitka spruce/blueberry association occurs inland from the coast along the lowland rolling hills (Table 4). Average elevation is 100 feet with flat to moderate slopes. Soils are moderately well-drained and well-developed.

3. *Picea sitchensis/Vaccinium spp-Oplopanax horridum*
PISI/VACCI-OPHO
Sitka spruce/blueberry-devil's club

Sitka spruce dominates this forest plant association (Table 1). Occasionally, mountain hemlock and western hemlock may be present. Sitka spruce reproduction is always present but sparse. The shrub understory is dominated by blueberry, devil's club, and salmonberry. Major herbs are five-leaf bramble, foamflower, and shield fern.

The Sitka spruce/blueberry-devil's club association occupies alluvial floodplains and uplifted beaches with flat to moderate slopes, average aspect of 109° and below 200 feet (Table 4). Soils are moderately well-drained and lack distinct horizons.

4. *Picea sitchensis/Vaccinium spp/Lysichitum americanum*
PISI/VACCI/LYAM
Sitka spruce/blueberry/skunk cabbage

Sitka spruce dominates the overstory with mountain hemlock or western hemlock as a minor associate (Table 1). The major reproduction seedling is Sitka spruce. The major shrub species is blueberry and salmonberry with a low percent cover of devil's club. The most important herbaceous species is skunk cabbage. Some of the minor herbs include five-leaf bramble, bunchberry, and foamflower.

Elevation for this association ranges from 0 to 100 feet, and nearly all plots are on lowland rolling hills or on alluvial floodplains with braided streams throughout (Table 4). Soils are poorly drained with perennial seeps throughout the stand.

5. *Picea sitchensis/Calamagrostis nutkaensis*
PISI/CANU3
Sitka spruce/Pacific reedgrass

Sitka spruce is the only conifer present except for an occasional western hemlock (Table 1). Sitka spruce and western hemlock reproduction is sparse. Pacific reedgrass is the major understory species along with various sedges and carex species. Blueberry and salmonberry are the dominant shrubs but with low percent covers.

Sitka spruce/Pacific reedgrass association forms predominantly on rocky headlands where exposure to salt spray and high winds is frequent (Table 4). Slopes range from flat to very steep (75%) with well-drained and well-developed soils.

6. *Picea sitchensis/Athyrium filix-femina*
PISI/ATFI
Sitka spruce/lady fern

Only Sitka spruce dominates the overstory and the reproduction in this association (Table 1). Understory consists of a luxuriant cover of lady fern. The minor herbs include skunk cabbage, oak fern, bunchberry, and foamflower.

Sitka spruce/lady fern association occupies the flat alluvial floodplains with braided streams throughout (Table 4). Soils are poorly drained and lack distinct horizons.

7. *Tsuga mertensiana/Vaccinium spp*
TSME/VACCI
Mountain hemlock/blueberry

Forests are dominated by mountain hemlock with a major component of Sitka spruce (Table 2). Occasionally western hemlock can be found in the overstory. Conifer seedlings and sapling cover consists of mountain hemlock, Sitka spruce, and western hemlock. A tall dense shrub layer of blueberry provides an understory along with rusty menziesia as a minor component extending from the lower valleys to steep side slopes. The most common herbaceous species are five-leaf bramble, bunchberry, and fern-leaf goldthread.

Mountain hemlock/blueberry association occupies coastal headwaters, lowland rolling hills, and steep sideslopes with various aspects (Table 4). Soils range from somewhat-poorly to well-drained.

8. *Tsuga mertensiana/Vaccinium spp-Cassiope mertensiana*
TSME/VACCI-CAME
Mountain hemlock/blueberry-martens cassiope

Mountain hemlock dominates this association, but Sitka spruce is a major component. Western hemlock may be found in the overstory but at low densities. The major reproduction seedlings are mountain hemlock but occasionally Sitka spruce and western hemlock are present. Blueberry is the major shrub component . With increasing elevation, martens cassiope and luetkea become an important associate in the shrub layer.

Mountain hemlock/blueberry/martens cassiope association occupies steep sideslopes at high elevations (>500 feet) on various aspects (Table 4). Soils are often stony and well-drained.

9. *Tsuga mertensiana/Vaccinium spp/Oplopanax horridum*
TSME/VACCI-OPHO
Mountain hemlock/blueberry-devil's club

The dominant overstory species in this association is Mountain hemlock with Sitka spruce as a major associate (Table 2). A sparse cover of Sitka spruce make up the conifer reproduction with an occasional mountain hemlock and western hemlock. The shrub layer is composed entirely of blueberry and salmonberry with islands of devil's club. The herbaceous layer includes five-leaf bramble, bunchberry, twisted stalk, foamflower, heart-leaf twayblade, and sphagnum.

Mountain hemlock/blueberry-devil's club association is most common on gentle sloping lowlands and rolling hills (Table 4). It generally is found at various aspects. Soils are moderately well-drained with a shallow organic layer (2 to 5 inches).

10. *Tsuga mertensiana/Vaccinium spp/Lysichitum americanum*
TSME/VACCI/LYAM
Mountain hemlock/blueberry/skunk cabbage

Mountain hemlock dominates the overstory with Sitka spruce as a minor component (Table 2). Mountain hemlock and Sitka spruce are the major conifer seedlings and saplings. Blueberry is the major shrub, although many others such as salmonberry, devil's club, and rusty menziesia may be present. The most important herb species in this association is skunk cab

bage. Other common herbs are goldthread, bunchberry, and sphagnum.

The mountain hemlock/blueberry/skunk cabbage association occupies lowland rolling hills with moderate slopes at elevations ranging from 100 to 250 feet (Table 4). Soils are poorly drained with organic layers 4 to 15 inches deep.

11. *Tsuga mertensiana/Vaccinium spp/Fauria crista-galli/Calamagrostis nutkaensis*
TSME/VACCI/FACR/CANU3
Mountain hemlock/blueberry/deer cabbage/ Pacific reedgrass

The dominant overstory species is mountain hemlock with Sitka spruce and western hemlock as minor components (Table 2). When present conifer reproduction consists of mountain hemlock, Sitka spruce, or western hemlock. Blueberry and copperbush are the dominant tall shrubs over a low shrub cover of crowberry and bog blueberry. The herb layer is dominated by deer cabbage with Pacific reedgrass and several other carex species and sedges as major components.

This association may be considered a transition between muskeg and forest because of its representative species from muskeg and forest associations. It occupies lowland rolling hills with moderate side slopes on various aspects, but southerly aspects are most common (Table 4). Soils are somewhat poorly drained with organic horizon ranging from 4 to 32 inches deep.

12. *Tsuga mertensiana/Cladothamnus pyrolaeflorus/Empetrum nigrum/Fauria crista-galli*
TSME/CLPY/EMNI/FACR
Mountain hemlock/copperbush/crowberry/deer cabbage

Mountain hemlock is dominant in the overstory, ranging from 500 to 600 years old, with a "krumholz" appearance (Table 2). Occasionally Sitka spruce and western hemlock are minor components. Important tall shrubs are blueberry and copperbush while the lower shrub layer is dominated by crowberry and bog blueberry, indicators of open forest and muskegs. Deer cabbage forms a substanial herb layer.

This association occupies flat or gentle convex knolls in muskegs with various aspects (Table 4). Soils are poorly drained, deep, and rich in organic matter.

13. *Tsuga heterophylla/Vaccinium spp*
TSHE/VACCI
Western hemlock/blueberry

Western hemlock dominates this association, although mountain hemlock or Sitka spruce are major components (Table 3). Western hemlock dominates conifer reproduction with occasional Sitka spruce and mountain hemlock. Blueberry is the major shrub with rusty menziesia and devil's club in small numbers. The herb layer includes five-leaf bramble, twisted stalk, bunchberry, foamflower, and heart-leaf twayblade.

This association occupies lowland rolling hills at an average elevation of 175 feet on various aspects (Table 4). Soils are somewhat poorly-drained with an organic layer averaging 8 inches in depth.

14. *Tsuga heterophylla/Vaccinium spp-Oplopanax horridum*
TSHE/VACCI-OPHO
Western hemlock/blueberry-devil's club

Western hemlock and Sitka spruce are major overstory species in this association (Table 3). Western hemlock dominates conifer reproduction. The shrub layer is composed entirely of blueberry with islands of devil's club. The herbaceous layer contains five-leaf bramble, bunchberry, twisted stalk, foamflower, heart-leaf twayblade, and sphagnum.

Western hemlock/blueberry-devil's club association is most common on lowland rolling hills with an aspect averaging 167° with various aspects (Table 4). Soils are moderately well-drained with shallow organic horizons.

15. *Tsuga heterophylla/Vaccinium spp/Lysichitum americanum*
TSHE/VACCI/LYAM
Western hemlock/blueberry/skunk cabbage

Western hemlock is dominant in the overstory with Sitka spruce as an important associate (Table 3). Mountain hemlock may be present in small numbers. Conifer reproduction consists of western hemlock and Sitka spruce. Major shrubs are blueberry and rusty menziesia. The herb layer is dominated by skunk cabbage with minor amounts of five-leaf bramble, bunchberry, and twisted stalk.

This association occupies various aspects on lowland rolling hills and wave cut platforms characterized by high water tables (Table 4). Elevations range from 0 to 100 feet. Soils are deep and poorly drained with moderate to thick organic layers ranging from 5 to 34 inches.

16. *Tsuga heterophylla/Vaccinium spp/Calamagrostis nutkaensis*

TSHE/VACCI/CANU3

Western hemlock/blueberry/Pacific reedgrass

The major overstory conifer of this association is western hemlock with mountain hemlock and Sitka spruce as a minor components (Table 3). In the understory blueberry dominates the shrub layer and Pacific reedgrass the herb layer. Typical herbs are bunchberry, five-leaf bramble, and deer fern.

Western hemlock/blueberry/Pacific reedgrass occupies lowland rolling hills at elevations ranging from 0 to 200 feet on various aspects (Table 4). Soil are somewhat poorly drained with organic horizons 5 to 21 inches in depth.

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Table 1. Sitka spruce series: Species cover and constancy by forest plant associations (number of plots=35).

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| Taxonomic Name | Common Name | Acronyms | PISI/ ALSI-VACCI | PISI/ VACCI | PISI/ VACCI-OPHO | PISI/ VACCI/ LYAM | PISI/ CANU | PISI/ ATFI |
| | | | %/% | | | | | |
| **Trees-overstory** | | | | | | | | |
| *Picea sitchensis* | Sitka spruce | PISI | 70/100 | 51/100 | 59/100 | 58/100 | 63/100 | 55/100 |
| *Tsuga heterophylla* | Western hemlock | TSHE | * | 27/60 | 20/22 | 20/16 | 23/50 | * |
| *Tsuga mertensiana* | Mountain hemlock | TSME | 5/33 | 31/60 | 21/44 | 30/33 | * | * |
| **Trees-understory** | | | | | | | | |
| *Picea sitchensis* | Sitka spruce | PISIU | 8/100 | 3/88 | 4/100 | 8/100 | 1/75 | 5/100 |
| *Tsuga heterophylla* | Western hemlock | TSHEU | 1/33 | 10/60 | 4/33 | 1/16 | 3/25 | * |
| *Tsuga mertensiana* | Mountain hemlock | TSMEU | 2/33 | 3/40 | 2/33 | 3/33 | * | * |
| **Shrubs** | | | | | | | | |
| *Alnus sinuata* | Sitka alder | ALSI | 18/100 | * | 1/11 | 2/66 | * | * |
| *Malus* | Crabapple | MAFU | 1/33 | * | * | 6/33 | * | * |
| *Menziesia ferruginea* | Rusty menziesia | MEFE | 1/33 | 4/80 | 1/66 | 8/50 | * | 2/100 |
| *Oplopanaz horridum* | Devil's club | OPHO | 18/100 | 3/100 | 16/100 | 2/100 | 4/100 | 3/100 |
| *Ribes bracteosum* | Current | RIBR | 20/33 | 3/10 | 9/33 | 5/16 | * | 11/66 |
| *Rubus spectabilis* | Salmonberry | RUSP | 10/33 | 4/80 | 20/100 | 6/100 | 4/100 | 1/100 |
| *Vaccinium* spp. | Blueberry | VACCI | 18/100 | 43/100 | 60/80 | 21/100 | 10/100 | 8/100 |

Table 1 continued.

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | PISI/ ALSI-VACCI | PISI/ VACCI | PISI/ VACCI-OPHO | PISI/ VACCI/ LYAM | PISI/ CANU3 | PISI/ ATFI |
| Taxonomic Name | Common Name | Acronyms | %/% | | | | | |
| **Herbs** | | | | | | | | |
| *Circaea alpina* | Enchanter's nightshade | CIAL | 2/33 | * | 3/33 | 8/33 | 4/25 | 2/33 |
| *Coptis asplenifolia* | Fern-leaf goldthread | COAS | * | 3/40 | 6/33 | 4/33 | * | 4/100 |
| *Cornus canadensis* | Bunchberry | COCA | 4/100 | 3/80 | 3/55 | 9/100 | 5/75 | 4/100 |
| *Listera cordata* | Heart-leaved twayblade | LICO | * | 2/70 | 2/44 | 1/50 | * | * |
| *Lysichitum americanum* | Skunk cabbage | LYAM | 3/33 | 6/20 | 8/33 | 25/100 | 1/25 | 13/100 |
| *Maianthemum dilatatum* | Berryberry | MADI2 | * | 2/20 | 1/11 | 1/16 | 2/50 | 1/33 |
| *Moneses uniflora* | Single delight | MOUN | * | 1/40 | 1/55 | 3/33 | 1/50 | * |
| *Osmorhiza purpurea* | Sitka sweet-cicely | OSPU | 1/33 | * | 1/11 | 1/16 | * | 1/100 |
| *Prenanthes alata* | Rattlesnake | PRAL | * | 1/20 | 1/33 | 1/50 | 2/75 | 1/100 |
| *Rubus pedatus* | Five-leaf bramble | RUPE | 3/100 | 6/100 | 6/88 | 6/66 | 1/100 | 2/100 |
| *Streptopus amplexifolius* | Twisted-stalk | STAM | 1/100 | 1/90 | 1/100 | 1/100 | 1/100 | 1/100 |
| *Tiarella trifoliata* | Tifoliate foamflower | TITR | 9/100 | 2/60 | 4/100 | 3/100 | 1/50 | 5/66 |
| *Veratrum viride* | False hellebore | VEVI | 1/33 | * | * | 4/16 | 1/50 | * |
| *Viola glabella* | Violet | VIGL | 6/66 | 5/20 | 5/33 | 1/50 | 5/50 | 2/100 |

Table 1 continued.

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATION | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | PISI/ ALSI-VACCI | PISI/ VACCI | PISI/ VACCI-OPHO | PISI/ VACCI/ LYAM | PISI/ CANU2 | PISI/ ATFI |
| Taxonomic Name | Common Name | Acronyms | %/% | | | | | |
| **Graminoids** | | | | | | | | |
| *Calamagrostis nutkaensis* | Pacific reedgrass | CANU3 | 2/66 | 3/20 | 5/11 | 9/33 | 46/100 | * |
| *Carex* spp. | Carex | CAREX | * | * | * | * | 48/100 | * |
| *Carex sitchensis* | Sitka sedge | CASI3 | * | * | 2/11 | 1/16 | * | * |
| *Trisetum* spp. | Oatgrass | TRSE | * | * | * | 15/16 | 18/50 | * |
| **Ferns** | | | | | | | | |
| *Athyrium filix-femina* | Lady fern | ATFI | 9/100 | 2/40 | 3/44 | 3/83 | 6/25 | 40/100 |
| *Blechnum spicant* | Deer fern | BLSP | * | 1/50 | 1/22 | 1/33 | 1/25 | 3/66 |
| *Dryopteris austriaca* | Spinulose shield fern | DRAU | 6/100 | 4/100 | 8/88 | 1/33 | 3/75 | 5/100 |
| *Gymnocarpium dryopteris* | Oak-fern | GYDR | 6/100 | 6/100 | 1/11 | * | 1/25 | * |
| *Thelypteris phegopteris* | Northern beech-fern | THPH | 6/66 | 2/30 | 5/55 | 6/66 | 3/50 | 14/100 |
| **Club Mosses** | | | | | | | | |
| *Lycopodium annotinum* | Stiff clubmoss | LYAN | 1/33 | 1/50 | 1/22 | 2/50 | * | * |
| *Lycopodium clavatum* | Running clubmoss | LYCL | 1/66 | 2/10 | 1/11 | 1/16 | * | * |
| *Lycopodium selago* | Fir clubmoss | LYSE | * | 1/50 | 11/77 | 1/66 | 1/50 | * |

Table 2. Mountain hemlock Series: Average cover and constancy by forest plant associations (number of plots=39).

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | TSME/ VACCI | TSME/ VACCI/ CAMI | TSME/ VACCI-OPHO | TSME/ VACCI/ LYAM | TSME/ VACCI/ FACR/ CANU3 | TSME/ CLPY-EMNI/ FACR |
| Taxonomic Name | Common Name | Acronyms | %/% | | | | | |
| **Trees-overstory** | | | | | | | | |
| *Picea sitchensis* | Sitka spruce | PISI | 18/90 | 21/90 | 19/100 | 15/100 | 5/88 | 5/100 |
| *Tsuga heterophylla* | Western hemlock | TSHE | 13/27 | 9/9 | * | * | 8/47 | 6/100 |
| *Tsuga mertensiana* | Mountain hemlock | TSME | 41/100 | 50/100 | 60/100 | 40/100 | 33/100 | 20/100 |
| **Trees-understory** | | | | | | | | |
| *Picea sitchensis* | Sitka spruce | PISIU | 9/100 | 2/81 | 8/100 | 15/100 | 4/94 | 1/85 |
| *Tsuga heterophylla* | Western hemlock | TSHEU | 9/27 | 2/18 | 3/40 | * | 3/47 | 3/10 |
| *Tsuga mertensiana* | Mountain hemlock | TSMEU | 5/90 | 3/90 | 2/100 | 6/50 | 8/94 | 1/14 |
| **Shrubs** | | | | | | | | |
| *Alnus sinuata* | Sitka alder | ALSI | 1/18 | 2/18 | * | * | 4/70 | 3/85 |
| *Cassiope mertensiana* | Martens cassiope | CAME | * | 3/100 | * | * | * | 1/14 |
| *Cladothamnus pyrolaeflorus* | Copperbush | CLPY | 3/18 | 2/27 | * | 2/50 | 7/100 | 24/100 |
| *Empetrum nigrum* | Crowberry | EMNI | * | * | * | * | 3/17 | 28/100 |
| *Luetkea pectinata* | Luetkea | LUPE | * | 3/100 | * | * | * | * |
| *Menziesia ferruginea* | Rusty menziesia | MEFE | 5/100 | 1/45 | 3/80 | 3/100 | 5/100 | 4/100 |

Table 2 continued.

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| Taxonomic Name | Common Name | Acronyms | TSME/ VACCI | TSME/ VACCI-CAME | TSME/ VACCI-OPHO | TSME/ VACCI/ LYAM | TSME/ VACCI/ FACR/ CANU3 | TSME/ CLPY-EMNI/ FACR |
| | | | %/% | | | | | |
| *Oplopanaz horridum* | Devil's club | OPHO | 1/90 | 3/90 | 10/100 | 1/100 | 2/70 | 1/14 |
| *Rubus spectabilis* | Salmonberry | RUSP | 5/90 | 2/100 | 6/100 | 3/100 | 3/100 | 3/28 |
| *Sorbus sitchensis* | Sitka mountain ash | SOSI | * | * | * | * | 2/58 | 1/71 |
| *Vaccinium spp.* | Blueberry | VACCI | 64/100 | 46/90 | 59/100 | 55/100 | 43/100 | 14/100 |
| *Vaccinium uliginosum* | Bog blueberry | VAUL | * | * | * | * | 5/11 | 9/57 |
| **Herbs** | | | | | | | | |
| *Coptis asplenifolia* | Fern-leaf goldthread | COAS | 8/72 | * | 6/60 | 13/100 | 6/94 | 7/100 |
| *Cornus canadensis* | Bunchberry | COCA | 6/90 | 1/90 | 7/80 | 8/100 | 9/100 | 8/100 |
| *Erigeron peregrinus* | Subalpine daisy | ERPE | * | * | * | * | 2/17 | 2/85 |
| *Fauria crista-galli* | Deer cabbage | FACR | 4/36 | * | * | 2/50 | 26/100 | 54/100 |
| *Habenaria* | Bog-orchid | HABEN | 2/18 | * | * | 1/50 | 1/58 | 1/71 |
| *Listera caurina* | Western twayblade | LICA | 1/18 | 1/9 | * | 1/50 | * | * |
| *Listera cordata* | Heart-leaved twayblade | LICO | 1/90 | * | 2/80 | 1/100 | 1/17 | 1/14 |
| *Lysichitum americanum* | Skunk cabbage | LYAM | 2/63 | * | 1/40 | 11/100 | 1/70 | 1/42 |
| *Moneses uniflora* | Single delight | MOUN | 1/63 | 1/54 | 1/60 | 1/50 | 1/5 | * |
| *Rubus pedatus* | Five-leaf bramble | RUPE | 6/100 | 5/100 | 8/100 | 4/100 | 5/88 | 4/85 |

Table 2 continued.

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | TSME/ VACCI | TSME/ VACCI-CAME | TSME/ VACCI-OPHO | TSME/ VACCI/ LYAM | TSME/ VACCI/ FACR/ CANU3 | TSME/ CLPY-EMNI/ FACR |
| **Taxonomic Name** | **Common Name** | **Acronyms** | %/% | | | | | |
| *Streptopus amplexifolius* | Twisted -stalk | STAM | 1/63 | 1/45 | 2/80 | 1/100 | 1/52 | 1/42 |
| *Tiarella trifoliata* | Trifoliate foamflower | TITR | 2/72 | * | 3/80 | 1/100 | 2/52 | 2/28 |
| *Veratrum viride* | False hellebore | VEVI | * | 2/36 | * | * | 2/58 | 1/57 |
| **Graminoids** | | | | | | | | |
| *Calamagrostis nutkaensis* | Pacific reedgrass | CANU3 | * | * | * | 4/50 | 21/100 | 8/42 |
| *Carex* spp. | Carex | CAREX | * | 2/36 | * | * | 6/69 | * |
| *Carex nigricans* | Blackish sedge | CANI2 | * | 2/18 | * | * | 5/10 | 14/71 |
| **Ferns** | | | | | | | | |
| *Athyrium filix-femina* | Lady fern | ATFI | 2/27 | 6/72 | 2/40 | 1/50 | 3/33 | 6/42 |
| *Blechnum spicant* | Deer fern | BLSP | 3/81 | 1/54 | 5/60 | 1/100 | 6/100 | 4/100 |
| *Dryopteris austriaca* | Spinulose shield fern | DRAU | * | 5/90 | 6/60 | 1/50 | 1/23 | * |
| *Gymnocarpium dryopteris* | Oak-fern | GYDR | 4/81 | 3/90 | 7/60 | 2/100 | * | 2/57 |
| *Thelypteris phegopteris* | Northern beech-fern | THPH | 1/27 | 2/63 | 9/60 | * | * | * |

Table 2 continued.

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | TSME/ VACCI | TSME/ VACCI-CAME | TSME/ VACCI-OPHO | TSME/ VACCI/ LYAM | TSME/ VACCI/ FACR/ CANU3 | TSME/ CLPY-EMNI/ FACR |
| Taxonomic Name | Common Name | Acronyms | %/% | | | | | |
| **Club Mosses** | | | | | | | | |
| *Lycopodium annotinum* | Stiff clubmoss | LYAN | 1/45 | * | * | * | * | |
| *Lycopodium clavatum* | Running clubmoss | LYCL | 1/27 | * | * | * | * | * |
| *Lycopodium selago* | Fir clubmoss | LYSE | 1/18 | 1/90 | 13/40 | * | * | * |
| Shagnum | Spagnum | SPHAG | 9/100 | 15/72 | 6/80 | 11/100 | 6/64 | * |

Table 3. Western hemlock Series: Species average cover and constancy by forest plant associations (number of plots=31).

| | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | |
|---|---|---|---|---|---|---|
| | | | TSHE/ VACCI | TSHE/ VACCI- OPHO | TSHE VACCI/ LYAM | TSHE/ VACCI/ CANU3 |
| **DOMINANT SPECIES** | | | | | | |
| **Taxonomic Name** | **Common Name** | **Acronyms** | %/% | | | |
| **Trees-overstory** | | | | | | |
| *Picea sitchensis* | Sitka spruce | PISI | 12/100 | 43/66 | 13/100 | 5/80 |
| *Tsuga heterophylla* | Western hemlock | TSHE | 50/100 | 57/100 | 55/100 | 35/100 |
| *Tsuga mertensiana* | Mountain hemlock | TSME | 16/68 | * | 9/75 | 16/100 |
| **Trees-understory** | | | | | | |
| *Picea sitchensis* | Sitka spruce | PISIU | 5/78 | 1/100 | 6/100 | 2/80 |
| *Tsuga heterophylla* | Western hemlock | TSHEU | 9/94 | 9/100 | 3/50 | 7/100 |
| *Tsuga mertensiana* | Mountain hemlock | TSMEU | 4/52 | * | 11/100 | 2/100 |
| **Shrubs** | | | | | | |
| *Alnus sinuata* | Sitka alder | ALSI | 2/10 | * | 1/25 | 10/20 |
| *Malus fusca* | Crabapple | MAFU | * | * | * | 9/40 |
| *Menziesia ferruginea* | Rusty menziesia | MEFE | 4/94 | 5/66 | 13/100 | 9/100 |
| *Oplopanax horridum* | Devil's club | OPHO | 1/94 | 7/100 | 2/50 | 1/100 |

Table 3 continued.

| DOMINANT SPECIES | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | |
|---|---|---|---|---|---|---|
| | | | TSHE/ VACCI | TSHE/ VACCI-OPHO | TSHE/ VACCI/ LYAM | TSHE/ VACCI/ CANU3 |
| Taxonomic Name | Common Name | Acronyms | %/% | | | |
| *Rubus spectabilis* | Salmonberry | RUSP | 4/89 | 2/100 | 3/100 | 6/100 |
| *Vaccinium* spp. | Blueberry | VACCI | 47/94 | 45/100 | 40/100 | 52/100 |
| **Herbs** | | | | | | |
| *Coptis asplenifolia* | Fern-leaf goldthread | COAS | 3/63 | 3/33 | 4/33 | 4/100 |
| *Cornus canadensis* | Bunchberry | COCA | 3/94 | 3/100 | 5/100 | * |
| *Listera cordata* | Heart-leaved twayblade | LICO | 2/89 | 1/100 | 3/75 | 1/60 |
| *Lysichitum americanum* | Skunk cabbage | LYAM | 1/36 | 1/33 | 10/100 | 3/100 |
| *Moneses uniflora* | Single delight | MOUN | 1/41 | 1/66 | 1/25 | 1/20 |
| *Rubus pedatus* | Five-leaf bramble | RUPE | 4/89 | 4/100 | 5/100 | 4/100 |
| *Tiarella trifoliata* | Trifoliate foamflower | TITR | 2/78 | 2/100 | 2/25 | 2/80 |
| *Viola glabella* | Violet | VIGL | 1/15 | 5/33 | * | 1/20 |
| **Graminoids** | | | | | | |
| *Calamagrostis nutkaensis* | Pacific reedgrass | CANU3 | 1/10 | * | 1/25 | * |
| *Carex* spp. | Carex | CAREX | 1/21 | * | * | * |

Table 3 continued.

| | | | COVER/CONSTANCY BY FOREST PLANT ASSOCIATIONS | | | |
|---|---|---|---|---|---|---|
| | | | TSHE/ VACCI OPHO | TSHE/ VACCI-LYAM | TSHE/ VACCI/ CANU3 | TSHE/ VACCI/ |
| **DOMINATE SPECIES** | | | | | | |
| **Taxonomic Name** | **Common Name** | **Acronyms** | | %/% | | |
| **Ferns** | | | | | | |
| *Athyrium filix-femina* | Lady fern | ATFI | 4/31 | 3/66 | 1/25 | * |
| *Blechnum spicant* | Deer fern | BLSP | 3/63 | 5/66 | 1/50 | 6/100 |
| *Dryopteris austriaca* | Spinulose shield fern | DRAU | 1/52 | 2/100 | * | * |
| *Gymnocarpium dryopteris* | Oak-fern | GYDR | 3/84 | 3/100 | 2/75 | 6/100 |
| **Club Mosses** | | | | | | |
| *Lycopodium annotinum* | Stiff clubmoss | LYAN | 1/21 | 1/33 | * | * |
| *Lycopodium selago* | Fir clubmoss | LYSE | 1/21 | 1/66 | 1/100 | * |
| Sphagnum | Sphagnum | SPHAG | 5/89 | 2/66 | 14/100 | 19/60 |

Table 4. Environmental summary of Montague Island Forest Plant Associations.

| FOREST PLANT ASSOCIATION | SURFICIAL LANDFORM | SLOPE DEPOSIT | ELEVATION (feet) | SLOPE DIRECTION (degrees) | SLOPE GRADIENT (%) | SOIL DEPTH (inches) | SOIL DRAINAGE CLASS[2] | SURFACE ORGANIC DEPTH (inches) |
|---|---|---|---|---|---|---|---|---|
| Sitka Spruce Series (number of plots = 35) | | | | | | | | |
| PISI/ALSI-VACCI | Active floodplains<br>Alluvial bottomland | Alluvium | 30 | 42 | 5 | 99 | SWP | 20 |
| PISI/VACCI | Lowland rolling hills | Alluvium<br>Colluvium | 100 | 160 | 30 | 30 | MW | 8 |
| PISI/VACCI-OPHO | Alluvial floodplains<br>Uplifted beaches | Alluvium<br>Beach deposits | 45 | 109 | 10 | 99 | MW | 8 |
| PISI/VACCI/LYAM | Alluvial floodplains | Alluvium | 17 | 54 | 10 | 99 | P | 45 |
| PISI/CANU3 | Rocky headlands | Undifferentiated | 90 | 88 | 43 | 35 | W | 7 |
| PISI/ATFI | Alluvial floodplains | Alluvium | 100 | 0 | 0 | 99 | P | 35 |
| Mountain Hemlock Series (number of plots = 53) | | | | | | | | |
| TSME/VACCI | Coastal headwaters<br>Lowland rolling hills | Beach deposits<br>Undifferentiated | 200 | 223 | 28 | 28 | MW | 7 |
| TSME/VACCI-CAME | Steep sideslopes | Colluvium | 800 | 180 | 50 | 16 | W | 5 |

Table 4 continued.

| FOREST PLANT ASSOCIATION | LANDFORM | SURFICIAL DEPOSIT | ELEVATION (feet) | SLOPE DIRECTION (degrees) | SLOPE GRADIENT (%) | SOIL DEPTH (inches) | 1SOIL DRAINAGE CLASS | SURFACE ORGANIC LAYER (inches) |
|---|---|---|---|---|---|---|---|---|
| TSME/VACCI-OPHO | Lowland rolling hills | Undifferentiated | 240 | 200 | 32 | 43 | MW | 4 |
| TSME/VACCI/LYAM | Lowland rolling hills | Alluvium | 250 | 119 | 7 | 99 | VP | 20 |
| TSME/VACCI/FACR/ CANU3 | Lowland rolling hills | Peat | 200 | 140 | 30 | 99 | SWP | 10 |
| TSME/CLPY/EMNI | Raised knolls in muskegs | Peat | 300 | 190 | 15 | 99 | VP | 35 |
| | | | | Western Hemlock Series (number of plots = 31) | | | | |
| TSHE/VACCI | Lowland rolling hills | Undifferentiated | 175 | 180 | 32 | 25 | SWP | 8 |
| TSHE/VACCI-OPHO | Lowland rolling hills | Alluvium | 125 | 167 | 35 | 99 | MW | 4 |
| TSHE/VACCI/LYAM | Lowland rolling hills<br>Wave cut platforms | Alluvium | 50 | 104 | 19 | 99 | P | 13 |
| TSHE/VACCI/CANU3 | Lowland rolling hills | Colluvium | 80 | 150 | 34 | 46 | SWP | 10 |

[1] Soil drainage: VP = very poorly drained; P = poorly drained; SWP = somewhat poorly drained; MW = moderately well; W = well drained.

# Soils and Plant Communities of Ultramafic Terrain on Golden Mountain, Cleveland Peninsula

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***Abstract.*** Ultramafic rocks are widely but sparsely distributed In Southeast Alaska. Three soils were sampled from dunite near the summit of Golden Mountain (773 m) to ultramafic and mixed, partially ultramafic, till on a spur ridge and a midslope bench, respectively, in order to characterize and classify them for comparison to other soils of southeast Alaska. The soils are in topographic and microclimatic sequences which are more pronounced than the parent material sequence. They are (1) a Cryochrept in an alpine meadow, (2) a Cryorthod in a transitional plant community, and (3) a Cryaquod in subalpine forest. Any of the 3 could be in either serpentinitic or oxidic families, depending on how they are interpreted in applying Soil Taxonomy. Neither of these soil mineralogy classes have been recognized in southeast Alaska previously. The forest-alpine transition appears to be lower in the ultramafic terrain of Golden Mountain than in other areas in southeast Alaska with similar climate, even though the plant communities are indistinguishable from ultramafic to other kinds of terrain. The Cryochrept has relatively high (neutral) pH values and reddish (7.5YR) hues, but the morphology of the leached Cryaquod is indistinguishable from soils of other plutonic and metamorphic terrain. The Fe contents are relatively high and the Ca/Mg ratios are very low in the soils of ultramafic terrain on Golden Mountain. Pine needles have very low Ca contents but normal Mg and Fe contents. Thus Ca deficiencies may be the tertiary cause of poor tree growth, after microclimate and soil drainage, in the ultramafic terrain of Golden Mountain, although Ni and Co toxicities are possible too.

Peridotite and serpentine are the common ultramafic rocks (Alexander et al., 1985). We refer to landscape in which they dominate as ultramafic terrain. Commonly, the soils and plant communities of ultramafic terrain are distinctly different from those of adjacent terrain (Alexander et al., 1985; Brooks, 1987). Even though they may be unique, we know of no special investigations of either the soils or the plant communities of ultramafic terrain in southeast Alaska. Ultramafic rocks are widely but sparsely distributed in southeast Alaska (Kennedy and Walton, 1946; Taylor and Noble, 1960). Small areas of ultramafic rock are exposed from Duke Island, at the southern border, northward throughout southeast Alaska. Generally, the soils on them are in classes (Soil Survey Staff, 1975) not recognized previously in soil resources inventories of southern Alaska (unpublished Forest Service and Soil Conservation Service manuscripts). Endemic plant species are common in ultramafic terrain (Brooks, 1987), but there are no known reports of any plant species that are restricted to ultramafic terrain in southeast Alaska (Paul Alaback, personal communication).

Three pedons were described and sampled on Golden Mountain, which has a core of dunite surrounded by other ultramafic rocks (Ruckmick and Noble, 1959), in order to characterize and classify them for comparison to other soils of southeast Alaska. One pedon is representative of the soils on peridotite bedrock around the summit of the mountain; another is representative of soils on till of ultramafic material; and the third is representative of soils on till of mixed, partially ultramafic, materials. Plant species and abundances were recorded in the immediate vicinity of each pedon.

## Environmental Setting

Golden mountain is near the tip of the Cleveland Peninsula, at 55 46 N and 132 03 W (Fig. 1). It is on the east end of a ridge 7 km long with altitudes from about 600 m in a saddle to 876 m on Mount Burnett. The west end of the ridge is adjacent to Union Bay. Soils and plant communities were sampled on the summit and the north-northeast flank of Golden Mountain (Table 1), which slopes about 4 km from 773 m at the summit to sea level at Vixen Inlet (Fig. 1).

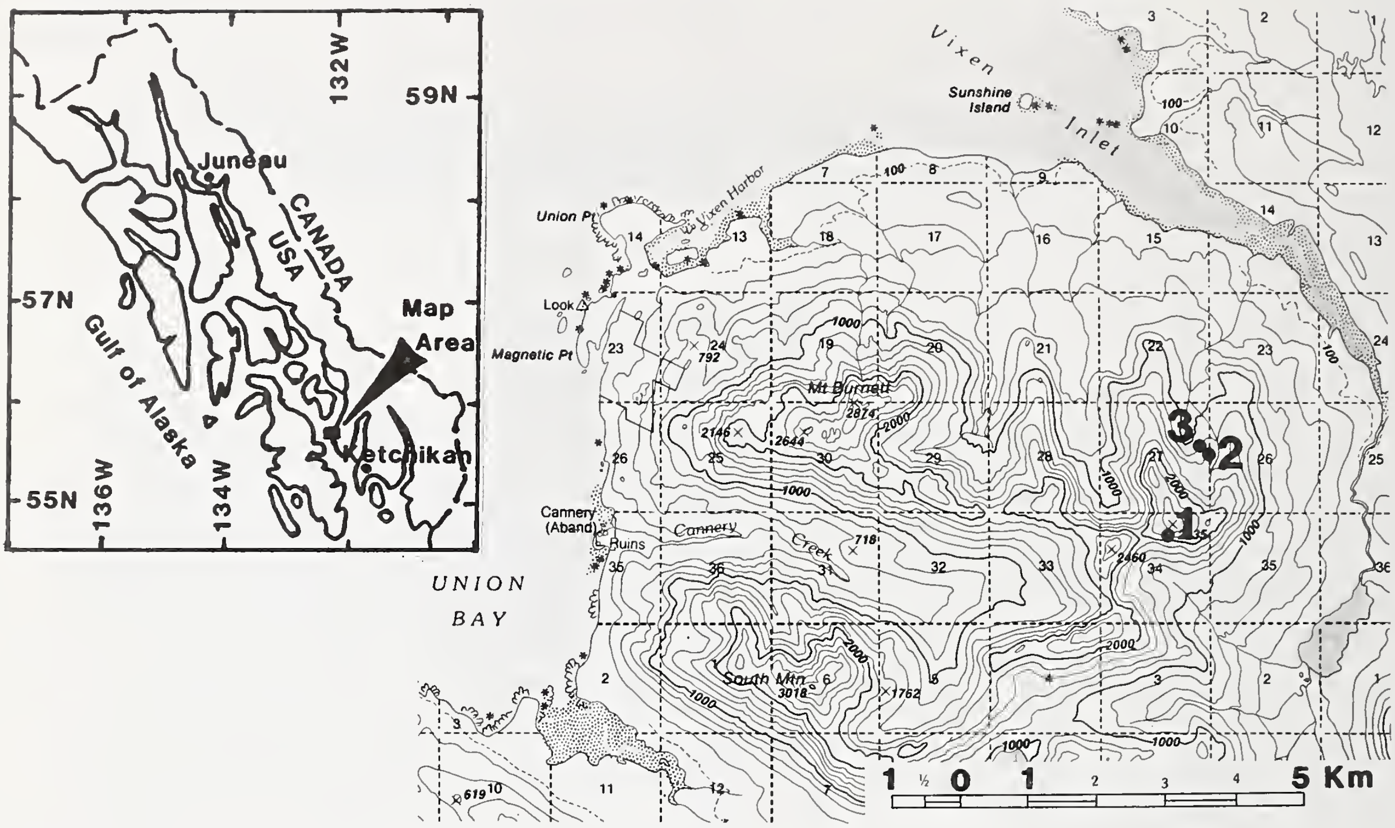


**Figure 1. Locations of Pedons 1, 2, and 3 on Golden Mountain.**

The Cleveland Peninsula was covered by a regional glacier carrying plutonic and metamorphic rocks from the northeast until a little more than $10^4$ years ago (Coulter et al., 1965; Mann, 1986). Subsequently, till was eroded from the summit of Golden Mountain and local Holocene glaciers deposited ultramafic till on the flanks of the mountain.

**Table 1. Pedon and environmental characteristics.**

| Pedon no. | Parent Material | Altitude | Slope: Position | Slope: Aspect | Slope: Grad. | Soil Drainage | Vegetation Type | Tree Ht.[1] |
|---|---|---|---|---|---|---|---|---|
| | | meters | | | % | class | | m |
| 1 | dunite | 740 | summit | SE | 1 | well | alpine meadow | 1 |
| 2 | ultramafic till | 420 | spur ridge | NNW | 50 | moderately well | subalpine meadow | 3 |
| 3 | mixed till | 370 | midslope bench | W | 55 | somewhat poor | subalpine forest | 20 |

[1]Height (meters) of dominant trees.

The current mean annual precipitation is about 200 to 250 cm. Mean precipitation exceeds evapotranspiration every month (Patric and Black, 1968). Soils near Juneau with very similar climate were found to have perudic soil moisture regimes (Patric and Stephens, 1968). Soil temperatures, based on experience in the Juneau area, are near 0 C during the winter and about 6 to 8 C at 50 cm depth during the summer. The soils at higher elevations may be warmer during the summer, due to less vegetative cover, but those at lower elevations are above 5 C for a longer period each year.

Forest and muskeg plant communities prevail at lower elevations and herbaceous alpine vegetation at higher elevations. This is a common vegetation pattern in southeast Alaska (Stevens, 1965), but the forest-alpine transition is lower on Golden Mountain than in areas with no ultramafic rocks nor any ultramafic till.

## Methods

Three soils were described (Table 2) and sampled by horizon (Soil Survey Staff, 1951). The vegetation was described on 0.0515 ha plots. Soil pH was determined with Truog indicator.

*Sand Characterization*

Sand fractions were separated by dry sieving following citrate-dithionite treatment. The fine sand (0.075-0.25 mm) was separated into light and heavy fractions with bromoform (SG=2.89). Magnetic grains were separated from the heavy fraction with a hand magnet. Approximately 100 grains were identified and counted from the light and nonmagnetic heavy separates of fine sand fractions from all inorganic soil horizons.

*Citrate-Dithionite Extract*

Approximately 0.75 g of sodium dithionite was added to 1.00 g of fine earth (soil < 2 mm) and 100 ml of 0.3 *M* sodium citrate in a 250-ml flask. The flask was shaken frequently, adding another 0.75 g of sodium dithionite after 20 hours to total about 1.5 g. After 40 hours, a few milliliters of solution was filtered into a small vial. A Perkin-Elmer model 303 atomic absorption spectrophotometer was used to determine Ca, Mg, Fe, Mn, Cr, Ni, and Co in the filtered citrate-dithionite (CD) extracts.

*Foliar Analyses*

Needles of the current and previous year were collected from the lower one-third of the crowns of pine (*P. contorta*) trees on August 20, 1987. They were oven dried and weighed. Nitrogen was determined by a microkjeldahl procedure. A subsample was ashed and digested with perchloric acid for elemental analyses on a Perkin-Elmer model 303 atomic spectrophotometer.

**Table 2. Pedon descriptions.**

| Hor. | Depth | Munsell Color | Field Grade | Structure | Consistence[1] | Roots | pH | Boundary |
|---|---|---|---|---|---|---|---|---|
| | cm | moist | | | moist, dry | | | |
| **Pedon 1 - coarse-loamy, oxidic Typic Cryochrept** | | | | | | | | |
| Oe | 4- 0 | | | | | | | as |
| A | 0- 3 | 7.5YR 3/4 | vfsl | 3vfgr | vfr,so | 1c,m;2f,vf | 6 | as |
| Bw | 3-14 | 7.5YR 4/5 | l | 1fsbk | fr,so | 1m;2f,1vf | 6.5 | gs |
| BC | 14-38 | 7.5YR 4/6 | fsl | 1msbk | fr,sh | 1vf | 6.5 | ds |
| C | 38-68 | 7.5YR 4/6 | lfs | Om | fr,so | none | 7 | as |
| R | 68+ | dunite bedrock | | | | | | |

[1]All horizons are slightly sticky and slightly plastic, except a nonplastic C horizon in pedon 1.

| Hor. | Depth | Munsell Color | Field Grade | Structure | Consistence[1] | Roots | pH | Boundary |
|---|---|---|---|---|---|---|---|---|
| | cm | moist | | | moist, dry | | | |
| **Pedon 2 - loamy, serpentinitic, shallow Typic ("Aquic") Cryorthod** | | | | | | | | |
| A | 0- 7 | 7.5YR 4/3 | l | 2vf,fsbk | vfr,so | 2vf | 6 | cs |
| E | 7-14 | 5YR 5/2 f1p 7.5YR 4/6 | l | 1fsbk | fr,vh | 1vf | 5.5 | aw |
| Bs | 14-21 | 7.5YR 4/6 | gsl | 2vfsbk | fr,sh | 1vf | 6.5 | gs |
| C | 21-28 | 7.5YR 5/5 | vgsl | Om | fr,sh | v1vf | 7.5 | aw |
| Cm1 | 28-30+ | 10YR 5/4 | | Om | efi | none | | |
| Cm2 | | 2.5Y 5/3 | an indurated layer sampled about 25 m from pedon 2 | | | | | |
| **Pedon 3 - loamy, mixed (or serpentinitic), shallow Sideric ("Aeric") Cryaquod** | | | | | | | | |
| Oe,Oa | 6-5-0 | 10YR 2/1 | | | | 1c,m;2f,vf | | as |
| E | 0- 2 | 10YR 4/1 | sl | Om | fr,sh | 2f,1vf | 4.2 | ab |
| Bhs | 2- 4 | 10YR 3/2 | sil | 1fsbk | fr,so | 1f;v1vf | 4.5 | cs |
| Bsg1 | 4-12 | 7.5YR 5/6 c1d 2.5Y 4/2 | sil | 1mpl | fr,sh | 1f;v1vf | 4.5 | gs |
| Bsg2 | 12-28 | 2.5Y 5/2 m1d 10YR 5/6 | sil | 1mpl | fr,sh | v1vf | 5 | gs |
| C | 28-46 | 5Y 5/2 m1d 10YR 5/6 | gl | Om | fi,h | none | 5 | cs |
| Cd | 46-50+ | 5Y 5/2 | gl | Om | vfi,vh | | | |

[1] All horizons are slightly sticky and slightly plastic, except a nonplastic C horizon in pedon 1.

**Table 3. Plants identified in the immediate vicinity of the 3 pedons.**

| Common Name | Taxonomic Name (Welsh, 1974) | Pedons | | |
|---|---|---|---|---|
| **Trees** | | | | |
| red alder | *Alnus rubra* | | | 3 |
| yellow cedar | *Chamaecyparis nootkatensis* | | 2 | 3 |
| Sitka spruce | *Picea sitchensis* | | | 3 |
| shore pine | *Pinus contorta* | 1 | 2 | |
| western red cedar | *Thuja plicata* | | | 3 |
| western hemlock | *Tsuga heterophylla* | | | 3 |
| mountain hemlock | *Tsuga mertensiana* | | 2 | 3 |
| **Shrubs** | | | | |
| Sitka alder | *Alnus sinuata* | | | 3 |
| mountain heather | *Cassiope mertensiana* | 1 | | |
| copper bush | *Cladothamnus pyrolaeflorus* | | | 3 |
| crowberry | *Empetrum nigrum* | 1 | 2 | 3 |
| common juniper | *Juniperus communis* | | 2 | |
| Labrador tea | *Ledum groenlandicum* | | 2 | |
| rusty menziesia | *Menziesia ferruginea* | | | 3 |
| yellow mountain heather | *Phyllodoce glanduliflora* | 1 | | 3 |
| Alaska blueberry | *Vaccinum alaskensis or ovalifolium* | | | 3 |
| dwarf blueberry | *Vaccinum caespitosum* | | | 3 |
| red huckleberry | *Vaccinum parvifolium* | | | 3 |
| bog blueberry | *Vaccinum uliginosum* | 1 | | |
| mountain cranberry | *Vaccinum vitus-idaea* | | | 3 |
| **Forbs** | | | | |
| yarrow | *Achillea borealis* | 1 | 2 | |
| anemone | *Anemone* spp | 1 | 2 | |
| aster | *Aster subspicatus* | 1 | | |
| marsh marigold | *Caltha* spp | 1 | 2 | 3 |
| harebell | *Campanula rotundifolia* | 1 | 2 | |
| indian paintbrush | *Castelleja unalaschensis* | 1 | 2 | |
| fernleaf goldthread | *Coptis asplenifolia* | | | 3 |
| bunchberry dogwood | *Cornus canadensis* | | | 3 |
| sundew | *Drosera* sp | | 2 | |
| deer cabbage | *Fauria crista-galli* | | 2 | 3 |
| strawberry | *Fragaria* sp | 1 | 2 | |
| alpine gentian | *Gentianna platypetala* | 1 | 2 | |
| caltha-leaf avens | *Geum calthifolium* | 1 | | |
| twayblade | *Listera caurina* | | | 3 |
| alpine azalea | *Loiseleuria procumbens* | 1 | 2 | |
| skunk cabbage | *Lysichitum americanum* | | | 3 |
| deerberry | *Maianthemum dilatatum* | | | 3 |
| five-leaf bramble | *Rubus pedatus* | | | 3 |
| twisted stalk | *Streptopus* sp | | | 3 |
| false hellebore | *Veratrum viride* | | | 3 |
| violet | *Viola glabella* | 1 | | |

| | | | | |
|---|---|---|---|---|
| **Grass-like Herbs** | | | | |
| grasses, sedges, rushes | *Graminae, Cyperaceae, Juncaceae* | 1 | 2 | 3 |
| **Ferns** | | | | |
| maidenhair fern | *Adiantum pedatum* | | 2 | |
| lady fern | *Athyrium filix-femina* | | | 3 |
| deer fern | *Blechnum spicant* | | | 3 |
| **Club Mosses** | | | | |
| stiff clubmoss | *Lycopodium annotinum* | 1 | | 3 |

## Results and Discussion

Soil parent material, microclimate, and drainage each differ in a sequence from pedon 1 on the summit of Golden mountain through pedon 2 on a spur ridge to pedon 3 on a midslope bench (Table 1). Pedon 1 is well drained due to its coarse texture and lack of till over fractured bedrock. Glacial till impedes drainage through pedons 2 and 3. Drainage restriction increases from pedon 2 to pedon 3 due partly to slope position and partly to increasingly finer soil materials from pedon 1 through pedon 3.

Aside from drainage, the obvious soil changes from pedon 1 through pedon 3 are declining pH and greater spodic horizon development (Table 2). The plant communities are dominated by forbs and grass-like herbs at pedon 1, grass-like herbs and dense patches of low shrubs and scrubby trees at pedon 2, and trees and high shrubs at pedon 3. These physiognomic differences and species composition (Table 3) of the plant communities appear to be related more closely to microclimatic differences and soil drainage than to soil pH and spodic horizon differences. The vegetation seems to affect podzolization more than Spodosol properties affect vegetation in this sequence. In Hokkaido, Nakata and Kojima (1987) found that conifer forests containing *Picea glehnii*, which extend to lower elevations on serpentinite, promoted podzolization where no Spodosols develop in broadleaf deciduous forests on sedimentary rocks and quartz schist.

Heavy, nonmagnetic, fine (0.075-0.25 mm) and medium (0.25-0.5 mm) sands dominate the fine earth of the C-horizons in pedons 1 and 2; olivine is predominant in the heavy fractions (Table 4). Thus, the soil parent materials of these pedons are ultramafic residuum (pedon 1) and ultramafic till (pedon 2). The light fraction of fine sand, which is the predominant size fraction, from the C-horizon of pedon 3 contains more quartz plus feldspar than serpentine plus chlorite. Thus the soil parent material of pedon 3 is mixed, only partially ultramafic, till.

There is no evidence of podzolization in pedon 1 on dunite. The soil is a coarse-loamy, oxidic Typic Cryochrept. No oxidic families have been recognized previously in southeast Alaska. This soil, however, has much more iron (Table 5) than required for oxidic families. Pedon 2 has an albic horizon, but also an A horizon. The A horizon is characteristic of alpine soils; it is absent from nearly all lower elevation Spodosols in southeast Alaska (Alexander et al., 1989). Generally, in alpine areas, A horizons are more developed in mafic (and ultramafic?) materials and E horizons in more siliceous materials (Romans et al., 1966). Pedon 3 with no A horizon is more typical of Spodosols in southeast Alaska, at least those of lower altitudes where most of the Spodosols occur. After initial relatively high pH values in ultramafic materials are reduced by leaching in cool humid (or perhumid) climates, podzolization may proceed normally with favorable vegetation (Nakata and Kojima, 1987).

Pedon 2 appears to have a silica-cemented till or pan, but there are no Durorthods nor any Duric subgroups in the Cryorthods. It might be presumed to be in a serpentinitic family. It does not have enough serpentine (and talc, Soil Survey Staff, 1975) to be in a serpentinitic family, but it has low Ca/Mg ratios characteristic of the family (Alexander et al., 1985). If olivine were included in the list of diagnostic minerals, then pedon 2 would be in a serpentinitic (or ultramafic) family. Pedon 3 might be in a serpentinitic family too, if the required quantity of diagnostic minerals were reduced to 0.15 g/g and determined in the 0.02-2 mm fraction (Alexander et al., 1985), but the diagnostic mineral content would be near the proposed limit.

**Table 4. Analyses of sand following citrate-dithionite treatment of the fine earth. Fine sand (0.075-0.25 mm) grains were counted in oils with refractive indices of 1.54 to 1.65.**

| | Sand in Fine Earth | | | | Fine Sand Fraction | | | Fine Sand Grain Counts[2] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | light | heavy | | heavy[3] | | | | | light[4] | | | |
| Hor. | vco | co | med | fine | | non magn. | magn.[1] | oliv. | pyr. | weath. unid. | hnbd. | garn. | serp. | weath. unid. | qtz. | feld. |
| | g/100g | | | | | | | specific counts/total | | | | | | | | |
| **Pedon 1** | | | | | | | | | | | | | | | | |
| A | tr | 3 | 15 | 27 | 2 | 93 | 5 | 0.9 | 0.1 | tr | - | - | 0.3 | 0.4 | 0.1 | tr |
| Bw | 1 | 4 | 8 | 7 | 3 | 82 | 15 | 0.6 | 0.05 | 0.3 | - | - | 0.1 | 0.9 | tr | tr |
| BC | <1 | 9 | 28 | 35 | 1 | 88 | 11 | 0.6 | 0.1 | 0.2 | - | - | 0.1 | 0.9 | tr | tr |
| C | tr | 7 | 32 | 41 | 1 | 93 | 6 | 0.7 | 0.15 | 0.1 | tr | - | 0.6 | 0.3 | tr | tr |
| **Pedon 2** | | | | | | | | | | | | | | | | |
| A | 4 | 12 | 10 | 16 | 57 | 34 | 9 | - | 0.6 | 0.2 | 0.15 | 0.05 | 0.05 | 0.15 | 0.7 | 0.05 |
| E | 2 | 4 | 6 | 18 | 71 | 26 | 3 | 0.05 | 0.6 | tr | 0.15 | 0.15 | 0.05 | 0.2 | 0.6 | 0.05 |
| Bs | 7 | 15 | 18 | 25 | 4 | 88 | 8 | 0.15 | 0.2 | 0.6 | - | - | 0.05 | 0.5 | 0.4 | tr |
| C | 2 | 10 | 20 | 37 | <1 | 97 | 3 | 0.3 | 0.5 | 0.15 | - | - | | | | |
| Cm1 | 3 | 12 | 22 | 38 | 5 | 88 | 7 | 0.8 | 0.1 | 0.05 | - | - | 0.1 | 0.9 | - | - |
| Cm2 | | | | | 28 | 66 | 6 | 0.8 | 0.15 | tr | - | - | 0.3 | 0.7 | tr | - |
| **Pedon 3** | | | | | | | | | | | | | | | | |
| O | | | | | | | | | | | | | 0.2 | 0.2 | 0.4 | 0.15 |
| E | 4 | 11 | 12 | 26 | 57 | 39 | 4 | 0.1 | 0.7 | - | 0.1 | 0.05 | 0.2 | 0.15 | 0.5 | 0.05 |
| Bhs | 3 | 4 | 7 | 17 | 54 | 38 | 8 | 0.1 | 0.7 | tr | 0.15 | 0.05 | 0.2 | 0.3 | 0.4 | 0.05 |
| Bsg1 | 2 | 4 | 6 | 17 | 60 | 35 | 5 | 0.1 | 0.7 | tr | 0.05 | 0.05 | 0.05 | 0.15 | 0.7 | 0.05 |
| Bsg2 | 2 | 4 | 7 | 18 | 53 | 40 | 7 | 0.1 | 0.7 | tr | 0.05 | 0.1 | 0.15 | 0.1 | 0.6 | 0.05 |
| C | 4 | 6 | 8 | 20 | 41 | 52 | 7 | 0.1 | 0.8 | tr | 0.05 | tr | 0.2 | 0.1 | 0.6 | 0.05 |
| Cd | 4 | 6 | 8 | 19 | 54 | 40 | 6 | 0.3 | 0.6 | tr | 0.05 | 0.05 | 0.3 | tr | 0.4 | 0.2 |

[1]Abbreviations: magn., magnetic; oliv., olivine; pyr., pyroxene (predominantly diopside (Ruckmick and Noble, 1959)); hnbd., hornblende; garn., garnet; serp., serpentine and chlorite; qtz., quartz; feld., feldspars; weath. unid., weathered unidentifiable.

[2]Symbols: -, nil or none; tr, 0.01 or 0.02.

[3]Minor heavy minerals (SG>2.89) - actinoite; epidote; clinozoisite.

[4]Minor light minerals (SG<2.89) - mica, mostly brown; glass, 0.1 in A horizon of Pedon 1.

Cemented till in pedon 2 and compact till in pedon 3 restrict drainage. The only evidence of restricted drainage in pedon 2 is few mottles in the albic horizon; but pedon 3 has a gleyed Bs horizon. Lacking Aquic and Aeric subgroups in the Cryorthods and Cryaquods, the most appropriate classes appear to be loamy, serpentinitic, shallow Typic (or Humic) Cryorthod for pedon 2 and loamy, serpentinitic, shallow Sideric Cryaquod for pedon 3. Oxidic families do not seem appropriate for Spodosols, because much of the iron is bound with organic matter rather than in hydrous oxides.

The Ca, Na, and Fe contents of the pine needles are very low (Table 6). There is little Ca in the soils (Table 5), but plenty of Fe. The N, P, Mg, K, and Zn contents of the pine needles are within normal ranges (Table 6). Foliar Mg contents are no higher in the soils of ultramafic terrain, at least not consistently higher, than in a Douglas Island muskeg on till or glaciofluvial deposits with no ultramafic components (Table 6). Thus Ca deficiencies appear to be more limiting than Mg toxicities in the pines of the ultramafic terrain, although Ni or Co toxicities are possibilities too.

**Table 5. Alkaline earth and transition elements in citrate-dithionite extracts from fine earth (soil < 2 mm).**

| Hor. | Depth | Ca | Mg | Ca/Mg | Fe | Mn | Cr | Ni | Co |
|---|---|---|---|---|---|---|---|---|---|
| | cm | ----g/kg---- | | mol ratio | ----g/kg---- | | --------mg/kg-------- | | |
| **Pedon 1** | | | | | | | | | |
| A | 0-3 | 0.37 | 1.80 | 0.13 | 131 | 2.3 | 2 | 43 | 19 |
| Bw | 3-14 | 0.22 | 1.31 | 0.10 | 126 | 6.4 | 3 | 45 | 24 |
| BC | 14-38 | 0.01 | 0.99 | 0.01 | 68 | 2.1 | 2 | 24 | 18 |
| C | 38-68 | 0.09 | 0.95 | 0.06 | 53 | 1.6 | 2 | 19 | 11 |
| **Pedon 2** | | | | | | | | | |
| A | 0-7 | 0.24 | 1.19 | 0.12 | 88 | 3.9 | 5 | 20 | 18 |
| E | 7-14 | 0.05 | 1.25 | 0.02 | 11 | 0.05 | 2 | 5 | 1 |
| Bs | 14-21 | 0.01 | 1.58 | <.01 | 82 | 2.4 | 7 | 19 | 23 |
| C | 21-28 | 0.02 | 2.04 | 0.01 | 34 | 1.0 | 3 | 17 | 5 |
| Cm1 | 28-30+ | 0.00 | 5.79 | <.01 | 18 | 0.5 | 1 | 33 | 2 |
| Cm2 | | 0.00 | 8.85 | <.01 | 15 | 0.5 | 1 | 21 | 3 |
| **Pedon 3** | | | | | | | | | |
| O | 6-0 | 0.92 | 0.87 | 0.64 | 9 | 0.1 | 2 | 6 | 4 |
| E | 0-2 | 0.10 | 0.11 | 0.59 | 5 | 0.03 | 2 | 5 | 5 |
| Bhs | 2-4 | 0.14 | 0.35 | 0.24 | 43 | 0.05 | 5 | 6 | 5 |
| Bsg1 | 4-12 | 0.14 | 0.60 | 0.14 | 42 | 0.2 | 5 | 6 | 6 |
| Bsg2 | 12-28 | 0.14 | 0.95 | 0.09 | 35 | 0.3 | 5 | 8 | 5 |
| C | 28-46 | 0.25 | 2.48 | 0.06 | 20 | 1.5 | 3 | 12 | 6 |
| Cd | 46-50+ | 0.31 | 3.33 | 0.06 | 12 | 0.6 | 1 | 9 | 6 |

**Table 6. Elemental content[1] (and rank, percentile)[2] of pine (*P. contorta*) needles.**

| Needle Age | N | P | Ca | Mg | K | Mn | Fe | Zn | Ca/Mg |
|---|---|---|---|---|---|---|---|---|---|
| year | g/kg | | | | | mg/kg | | | mol ratio |
| **Pedon 1** | | | | | | | | | |
| current | 17.0(89) | 1.61(88) | 0.88(00) | 1.21(70) | 5.8(79) | 134(56) | 58(00) | 34(40) | 0.44 |
| previous year | 11.2(41) | 0.76(68) | 1.46(00) | 1.19(58) | 3.3(45) | 170(55) | 122(07) | 24(00) | 0.74 |
| **Pedon 2** | | | | | | | | | |
| current | 10.0(34) | 1.06(74) | 0.90(00) | 1.01(50) | 5.2(70) | 450(93) | 24(00) | 36(42) | 0.54 |
| previous year | 7.4(08) | 0.55(45) | 2.08(00) | 1.14(56) | 2.7(28) | 985(96) | 33(00) | 48(48) | 1.11 |
| **Pedon 3[3]** | | | | | | | | | |
| current | 11.9(59) | 1.50(86) | 0.86(00) | 0.91(35) | 8.5(98) | 127(53) | 68(00) | 32(36) | 0.57 |
| previous year | 10.1(40) | 0.69(61) | 1.92(00) | 0.65(07) | 3.9(62) | 220(63) | 36(00) | 36(25) | 1.79 |
| **Douglas Is. muskeg[4]** | | | | | | | | | |
| current | 11.6(55) | 1.22(78) | 1.31(19) | 1.07(57) | 6.5(88) | 274(83) | 36(00) | 43(49) | 0.74 |
| previous year | 8.2(15) | 0.69(60) | 2.18(06) | 0.81(23) | 3.7(56) | 380(79) | 40(00) | 42(40) | 1.63 |

[1]Mass of element/mass of oven dry needles.

[2]The rank (percentile) among trees sampled throughout the range of *P. contorta*.

The Na contents of needles from all sites are very low - about percentile 5 for current needles and 10 for needles of the previous year.

[3]A pine tree about 10 m tall sampled about 100 m northeast of pedon 3.

[4]A pine tree about 3 m tall sampled on a Saprist 150 m (altitude) above the Gastineau Channel.

## Conclusion

The parent materials of the 3 pedons sampled on Golden mountain are in a sequence from pedon 1, the most ultramafic, to pedon 3, the least ultramafic. Also, they are in topographic and microclimatic sequences which are more pronounced than the parent material sequence. The forest-alpine transition appears to be lower in the ultramafic terrain of Golden Mountain than in other areas in southeast Alaska with similar climate, even though the plant communities are not clearly distinguishable from ultramafic to other kinds of terrain. Subgroups of soils in ultramafic terrain are the same as those in other kinds of terrain; but the soil mineralogy classes are serpentinitic or oxidic, which have not been reported in other kinds of terrain in southeast Alaska. The Fe contents are high and the Ca/Mg ratios are very low in the soils of ultramafic terrain on Golden Mountain. Pine needles have very low Ca contents but normal Mg contents. Thus Ca deficienes may be the cause of poor tree growth in the ultramafic terrain of Golden Mountain, although Ni and Co toxicities are possible too.

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# Development of Wetlands Mapping Procedures For Forest Planning in Southeast Alaska

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***Abstract.*** To meet forest planning needs in southeast Alaska, wetlands were defined using a modification of the Level I three-parameter approach employed by the U.S. Army Corps of Engineers. To identify wetlands, an existing soils-forested plant association data base was used. Plant species were ranked as to wetland status. Average areal cover of plant species in each wetland status category was determined. A weighted comparison of wetland vs. upland scores was used to designate each association as wetland or non-wetland. Although data for non-forest associations was incomplete, designation was drawn from previous studies. Plant associations were related to hydric soils. Soils were then related to map units in existing computerized soil maps. Wetland boundaries were generated from existing soil maps in a geographic information system (GIS). Wetland habitats were classified according to an approach employed by the U.S. Fish and Wildlife Service. Resulting maps were sufficiently accurate for forest-level planning requirements. Wetland maps from Forest Service data were compatible with maps prepared by the Fish and Wildlife Service's National Wetlands Inventory.

Wetlands are defined by the Corps of Engineers (1987) as "those areas that are inundated by surface or ground water with a frequency sufficient to support, and under normal circumstances, do or would support, a prevalence of vegetation or aquatic life that requires saturated or seasonally saturated soil conditions for growth and reproduction. Wetlands generally include swamps, marshes, bogs, and similar areas such as sloughs, potholes, wet meadows, river overflows, mud flats, and natural ponds." Designation of wetlands has been less clearly specified, and federal agencies have devised a number of approaches (Corps of Engineers, 1987; Sipple,1987; Cowardin et al., 1979).

Wetlands comprise a major portion of the southeast Alaska landscape. Excessive precipitation (1500-4000 mm/yr) and extensive areas of young (late Quaternary) glacial terrain have resulted in abundant wetlands.

The Tongass National Forest comprises a substantial portion of southeast Alaska. Its 6.7 million ha (16.8 million acres) represent an area three times the size of the state of Massachusetts. Such a vast area presents challenges in forest planning. The Tongass Land Use Management Plan, now under revision, requires wetlands information during assessment of management options and impacts. Limited time, financial, and personnel resources necessitate a wetlands mapping scheme that could be developed from existing soil inventory and plant association plot databases.

Batten et al. (1978) prepared a comprehensive description of the flora of southcentral Alaska wetlands. Such a study for southeast Alaska is lacking. Although some data collection in non-forest wetlands has been conducted as part of doctoral studies (e.g., Fox, 1983) or planning efforts (e.g., Morrison, 1984), these studies covered only small portions of the entire Tongass. Further, they did not include forested wetland types. To our knowledge, no comprehensive field data collection of forested wetland types in southeast Alaska had been conducted prior to our investigation.

In defining wetlands, a three-parameter approach has been adopted by the Corps of Engineers (1987). Soil, hydrology, and vegetation must all be hydric for an area to be considered wetland.

Hydric soils are "saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation" (National Technical Committee for Hydric Soils, 1987). The unique, high precipitation environment of southeast Alaska warrants special consideration. Soils are wet virtually year-round. The degree of wetness is determined by storm duration, topography, and subsurface structures restricting or aiding soil drainage (Swanston 1974, Forest Service 1980).

Continual wetness is not necessarily saturation, however. Saturation is a condition where all voids (pores) between soil particles are filled with water. Many southeast soils (particularly those derived from alluvium or colluvium materials) are continually wet but remain aerobic because water is moving through the soil profile. Alluvial soils are good examples, as are many soils on relatively steep slopes.

Hydrology is usually the most imprecise of the three parameters. Most wetland hydrology definitions include evidence of flooding, plant physiological adaptation, or frequency and duration of flooding for identification. (Corps of Engineers, 1987). Because of the maritime climate and continuous moist conditions in southeast Alaska, the hydrology parameter had to be

defined using one of the other parameters. In this paper, wetland hydrology will be inferred from soils; i.e., if a soil is hydric, the hydrology parameter will be considered hydric.

Vegetation is often the most challenging of the three parameters to evaluate, particularly in forest ecosystems. Most tree species dominating southeast Alaska forested wetlands are found on uplands with equal frequency. We have therefore developed procedures to determine hydrophytic status of forested communities, and to relate this to existing computerized soil maps. Procedures are outlined as a flowchart in Figure 1.

```
Plant Association                          Soils
      Database                             Database
          |                                    |
          |                                    |
          |                                    |
Determination                         Determination
of Hydric                             of Hydric
Plant Association                     Soils and Hydrology
          |                                    |
          |                                    |
          |                                    |
Frequency of Hydric               Wetland Determination (yes/no)
Plant Associations for            For Each Hydric Soils Series
Each Soils Series                              |
          |                                    |
          |                                    |
    -------------------------------------------------
                         |
                         |
                         |
               Hydric and Mixed
               Soils Map Units
                    Identified
                         |
                         |
                         |
          Classify Each Map Unit as to
          Wetland Habitat Type, Based
               on Cowardin et al. (1979)
                         |
                         |
                         |
          Assign Wetland Habitat Codes
          To Soil Coverages (Computerized
                    Maps in GIS)
                         |
                         |
                         |
               Generate Wetland Maps
               Calculate Estimated
               Wetlands Areas etc.
```

**Figure 1. Decision diagram for wetland mapping codes determination.**

## Methods

*Determination of Hydric Soils*

Information needed to determine hydric soils was derived from soil inventory data collected by the Forest Service during National Cooperative Soil Surveys (NCSS), conducted on all three Areas of the Tongass National Forest.

Characteristics for each soil series were evaluated using specific criteria provided by the Soil Conservation Service, as outlined on p. 26-34 of the Corps' manual. Those soils that meet the hydric characteristics are listed in Table 1 along with the specific criteria determining each soils' hydric condition.

*Vegetation*

Forested vegetation data were used from vegetation surveys conducted in the summers of 1986 and 1987 to develop a plant association classification for the southern administrative area of the Tongass National Forest, known as the Ketchikan Area. (Comparable wetlands data collection, analysis, and determinations were conducted for the other two Areas of the Tongass National Forest, but for the sake of brevity are not detailed here.)

**Table 1. Hydric soils of the Ketchikan Area, and criteria used in their evaluation. Criteria follow Soil Survey Staff (1975) guidelines.**

| | Evaluation Criteria[2] | | | |
|---|---|---|---|---|
| | | Depth to water table for the surface for more than 1 week during growing season | | |
| Soil Series | Histosols (except Folists) | Less than 0.5 ft. (somewhat poorly drained) | Less than 1.0 ft. (permeability >6 in/hr) (very poorly or poorly drained) | Less than 1.5 ft. (permeability <6 in/hr) (very poorly or poorly drained) |
| Golden | | | | X |
| Grindall | X | | | |
| Helm | | | | X |
| Hofstad | | | | X |
| Hydaburg[1] | X | | | |
| Isidor | | | | X |
| Kaikli[1] | X | | | |
| Karheen[1] | X | | | |
| Kina[1] | X | | | |
| Kitkun | | | | X |
| Kogish[1] | X | | | |
| Magnetic | | X | | |
| Maybeso[1] | X | | | |
| Mears | | | | X |
| Mitkof | | X | | |
| Petrel | | X | | |
| St. Nicholas | | | X | |
| Southmountain | | X | | |
| Staney[1] | X | | | |
| Sunnyhay[1] | X | | | |
| Wadleigh | | | | X |

[1]Noted as hydric by the National Technical Committee for Hydric Soils (1987) or Appendix D of Corps of Engineers (1987). Other soil series in this list may be added to these documents when final correlation of the soil inventories are completed.

[2]An "X" indicates soil-determining characteristic.

Vegetation areal cover data were collected using a releve approach (Barbour et al., 1980). Circular 12.8 m (42 ft.) radius plots were used. Areal cover was ocularly estimated and recorded as percentages of the plot area. Plots were selected using a reconnaissance approach (Pfister et al., 1977). Throughout the entire non-wilderness portion (approximately 1.2 million ha, or 3 million ac) of the Ketchikan Area, 785 forested plots were sampled. In addition to plant cover data, the soil series was identified at each plot, and in most plots a soil profile was described. Plant association determinations were thus directly linked to soils. Plant associations were determined using an interim classification key (West and Martin, 1987/unpublished). Only old-growth forest plots were sampled.

*Determination of Hydrophytic Vegetation*

The Corps of Engineers (1987)approach to the vegetation parameter designation is to consider the parameter hydric if 50 percent or greater of vegetative cover is adapted to wetland (saturated soil) conditions. Plant species are assigned to one of five classes along a gradient from wetland to upland.

| | |
|---|---|
| OBL | Obligate wetland species; those always (> 99% frequency) found with saturated soil conditions. |
| FACW | Facultative wetland species; usually, but not always (>67% to 99% frequency) on saturated soils. |
| FAC | Facultative species; found on both wetlands and nonwetlands with equal frequency (33%-67%). |
| FACU | Facultative upland species; usually (>67% to 99% frequency), but not always, found on upland sites. |
| UPL | Upland species; always (frequency >99%) found on nonwetland sites. |

For delineation, the Corps generally considers wetland plants to be either FAC, FACW, or OBL species. If the sum cover total of these species is 50 percent or greater, then the site is called a wetland *for the vegetation parameter*. Thus the species dominating forest wetlands are not clearly associated with hydric character. Soil and hydrology parameters must then be cross-referenced to confirm presence of a wetland. However, by definition FAC species have equal frequency on wetlands and non-wetlands (U.S. Army Corps of Engineers, 1987; Sipple, 1987). All common tree species in southeast Alaska, except Sitka spruce, are considered facultative (FAC) (Reed, 1988). Spruce is designated facultative upland (FACU).

Use of species with greater fidelity to either wetlands or uplands is appropriate if the obligates (OBL) are believed to better indicate wetlands vs. uplands than the facultatives (Wentworth and Johnson, 1986). In other words, they serve as better indicators of wetland conditions. We therefore consider FAC species neutral, contending that dropping of FAC species in calculations results in more accurate wetland determinations. Because species are weighted in proportion to their frequency in wetlands, the gradient of habitats from wetland to upland is better described. Greater emphasis on indicators, rather than dominating species, characterizes this approach (hereafter referred to as the "Forest Service approach")[1].

Average areal cover of each species for each plant association was generated using a computer package (Volland and Connelly, 1978). To determine average areal cover, all plots for a plant association were used. For example, if an association had ten sample plots, and a species showed 3 percent cover on only one plot of the ten, the average percent cover of that species would be 0.3.

Each species' wetland status (FAC, FACW, etc.) was then designated using the U.S. Fish and Wildlife Service list for Alaska (Reed, 1988). Because FAC species dominate the overstory of southeast Alaska forest ecosystems we considered them neutral. Evaluation of the vegetation parameter was therefore influenced more by species showing greater fidelity to wetlands or non-wetlands.

A tally of wetland (FACW and OBL) versus upland (FACU and UPL) species cover indicated the relative importance of hydrophytic versus non-hydrophytic vegetation. UPL and OBL species were weighted twice as much as the respective FACU and FACW species. FAC species were considered neutral, or given zero weight. The assigned weights were therefore OBL=2, FACW=1, FAC=0, FACU=1 and UPL=2.[2]

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[1]"Forest Service" here serves as a convenient term. It refers only to the Tongass National Forest, and not to the entire National Forest System.

[2]For comparison, weights used in the Fish and Wildlife Service (FWS) approach are OBL=1, FACW=2, FAC=3, FACU=4 and UPL=5. Use of either approach yields the same wetland determination.

A wetland vegetation index, although not necessary to determine wetlands, was developed in order to rank plant associations along a wet-dry gradient. The index is equal to the ratio of the wetland vegetation score to the upland vegetation score. A ratio greater than one indicates wetland vegetation. For example, consider the Hemlock/Blueberry/Skunk Cabbage plant association (TSHE/VACCI/LYAM) (Table 2). The ratio of the hydrophytic plant association score (46.9) to the upland vegetation score (37.5) is 46.9/37.5, or 1.25. The index is greater than 1.00 and therefore indicates a hydrophytic association.

Wetlands are delineated by habitat type. To designate different wetland types, the Fish and Wildlife Service's classification (Cowardin et al., 1979) is followed, with modifications where necessary. The Cowardin approach provides a comprehensive classification of wetland types and is used in the National Wetlands Inventory.

*Development of Interpretive Wetland Maps*

Following designation of wetland habitats, soil map units were evaluated as to wetland character. First, the soil series present in each map unit were designated hydric or non-hydric based on criteria discussed above. Plant association sample plots for each soil series were then tallied to determine the soil series' corresponding vegetation. Soil series meeting hydric soil conditions with greater than 50% hydric sample plots were considered wetlands. For example, if 20 plant association sample plots were available for a soil series, and 13 were hydrophytic, then 13/20 (65%) were wetland and the hydric soil series was considered wetland.

Because soil map units are often combinations of two or more soils, plus miscellaneous areas, determining the wetland character of map units involved consideration of all their components. Soil map units were then designated either wetland, non-wetland, or mixed. These designations were determined by the following criteria:

a. Soil map units composed of 60% or greater hydric soils, with hydrophytic vegetation, are considered wetland units;

b. Soil Map units with hydric soils and hydrophytic vegetation covering 30 to 59 percent of the unit are considered mixed with upland soils and vegetation; and

c. Soil map units with less than 30 percent of the map unit designated wetland are considered non-wetland.

Wetland habitat type designations were then assigned to each map unit, following the scheme developed by Cowardin et al. (1979). Even though vegetation field data were unavailable for non-forest wetlands, habitat type designations were based on the work of Fox (1983) and Morrison (1984).

Wetland codes were then assigned to pre-existing digitized soil maps in the ARC/INFO (ESRI, 1988) geographic information system. Because data tables can be related to each soil map unit, maps can be printed and summary statistics can be calculated for survey areas.

**Results and Discussion**

Analysis of vegetation of forested plant associations as to wetland character is summarized in Table 2. If the wetland indices are ranked from most hydric to least hydric (Table 3), a clearer picture emerges of the gradient from wetland to upland.

In comparing this with a weighted average approach using facultative species (Table 4), it is evident that an approach without facultative species yields more spread or range. This range is considered a wetland gradient. All weighted average scores with facultative species fell in the range of 2.5-3.5.
With only interpretation of aerial photography values in this range are considered uncertain as wetland or non-wetland, and must be further investigated in the field (Hall, 1988).

Wetland habitat types used in mapping are presented in Table 5. These follow the Cowardin et al. (1979) classification as closely as possible. Note the large number of map units that are of mixed wetland/ non-wetland character.

A wetland map generated using this approach was compared with a wetland map prepared as a result of the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI). Results were similar, although maps generated by this (Forest Service) approach and NWI have different resolutions due to map scale differences and mapping approaches. NWI maps are developed from interpretation of vegetation types from small-scale colored aerial photographs (1 inch per mile). NWI areas proving difficult to interpret are field-checked. Wetland classification and maps produced from the approach presented in this paper are based on soils and plant association data. Wetlands are not mapped directly but are developed from detailed (Order 3) soil inventory data on 4-inch-to-the-mile colored photography. Vegetation data is related to the soils information, as it was collected concurrently.

**Table 2. Hydrophytic Vegetation Determination Summary - Forested Plant Associations. Designations are for the vegetation parameter only.**

| Plant Association[1] | Areal Cover (Percent) UPL | FACU | FACW | OBL | Upland Vegetation Score | Total No. Upland Species | Wetland Vegetation Score | Total No. Wetland Species | Wetland Vegetation Designation | Wetland Vegetation Index |
|---|---|---|---|---|---|---|---|---|---|---|
| TSHE/VACCI | 5.2 | 25.3 | 0.9 | 9.1 | 35.7 | 18 | 19.1 | 8 | Non-Wetland | 0.54 |
| TSHE/VACCI/DRAU2 | 2.4 | 32.5 | 1.1 | 3.9 | 37.3 | 16 | 8.9 | 7 | Non-Wetland | 0.24 |
| TSHE/VACCI/LYAM | 8.2 | 21.1 | 1.9 | 22.5 | 37.5 | 18 | 46.9 | 11 | Wetland | 1.25 |
| TSHE/VACCI-OPHO (HP) | 2.5 | 50.1 | 3.3 | 4.1 | 55.1 | 16 | 11.5 | 13 | Non-Wetland | 0.21 |
| TSHE/VACCI-OPHO (MP) | 1.0 | 80.0 | 5.0 | 6.0 | 82.0 | 10 | 17.0 | 3 | Non-Wetland | 0.21 |
| TSHE/OPHO | 1.8 | 77.0 | 5.2 | 2.6 | 80.6 | 15 | 10.4 | 8 | Non-Wetland | 0.13 |
| | | | | | | | | | | |
| TSHE-CHNO/VACCI | 9.3 | 24.6 | 4.8 | 6.4 | 43.2 | 17 | 17.6 | 17 | Non-Wetland | 0.41 |
| TSHE-CHNO/VACCI/LYAM | 12.1 | 25.8 | 4.1 | 22.1 | 50.0 | 19 | 48.3 | 11 | Non-Wetland | 0.97 |
| TSHE-CHNO/VACCI-OPHO | 9.5 | 71.0 | 0.0 | 4.0 | 89.0 | 12 | 8.0 | 2 | Non-Wetland | 0.09 |
| | | | | | | | | | | |
| PISI/VACCI | 3.7 | 61.5 | 4.4 | 7.7 | 68.9 | 17 | 19.8 | 14 | Non-Wetland | 0.29 |
| PISI/VACCI-OPHO | 2.9 | 94.8 | 0.9 | 3.5 | 100.6 | 17 | 7.9 | 12 | Non-Wetland | 0.08 |
| PISI/OPHO | 2.5 | 98.6 | 7.2 | 2.3 | 103.6 | 17 | 11.8 | 12 | Non-Wetland | 0.11 |
| PISI/OPHO-RUSP | 0.7 | 137.6 | 4.1 | 6.0 | 139.0 | 9 | 16.1 | 7 | Non-Wetland | 0.12 |
| PISI/OPHO-LYAM | 3.2 | 81.2 | 5.7 | 14.2 | 87.6 | 16 | 33.9 | 14 | Non-Wetland | 0.39 |
| PISI/ALNUS | 0.6 | 97.1 | 19.4 | 14.7 | 98.3 | 16 | 48.8 | 19 | Non-Wetland | 0.50 |
| PISI/VACCI/LYAM | 10.0 | 79.5 | 3.1 | 27.2 | 99.5 | 18 | 57.5 | 7 | Non-Wetland | 0.58 |
| | | | | | | | | | | |
| MXD CON/VACCI | 8.8 | 21.9 | 1.6 | 7.4 | 39.5 | 21 | 16.4 | 13 | Non-Wetland | 0.42 |
| MXD CON/VACCI/LYAM | 9.7 | 25.8 | 8.3 | 27.2 | 45.2 | 15 | 62.7 | 21 | Wetland | 1.39 |
| MXD CON/VACCI/FACR | 11.6 | 17.7 | 24.6 | 17.0 | 40.9 | 20 | 58.6 | 25 | Wetland | 1.43 |
| MXD CON/GASH/FACR | 6.6 | 15.1 | 20.0 | 13.7 | 28.3 | 19 | 47.4 | 24 | Wetland | 1.67 |
| MXD CON/VACCI-GASH | 7.1 | 3.5 | 5.2 | 4.3 | 17.7 | 15 | 13.8 | 22 | Non-Wetland | 0.78 |
| MXD CON/GASH/LYAM | 3.2 | 12.6 | 5.9 | 21.4 | 19.0 | 12 | 48.7 | 17 | Wetland | 2.56 |
| MXD CON/GASH | 5.3 | 10.5 | 1.7 | 4.9 | 21.1 | 17 | 11.5 | 12 | Non-Wetland | 0.55 |
| | | | | | | | | | | |
| TSME/VACCI | 4.6 | 20.8 | 2.2 | 8.0 | 30.0 | 23 | 18.2 | 17 | Non-Wetland | 0.61 |
| TSME/VACCI-CLPY | 7.9 | 16.0 | 9.1 | 7.4 | 31.8 | 20 | 23.9 | 16 | Non-Wetland | 0.75 |
| TSME/VACCI-CAME | 19.4 | 17.1 | 12.3 | 6.2 | 55.9 | 20 | 24.7 | 16 | Non-Wetland | 0.44 |
| TSME/VACCI/VEVI | 6.9 | 23.8 | 7.7 | 9.9 | 37.6 | 27 | 27.5 | 21 | Non-Wetland | 0.73 |

**Table 2 (Continued).**

| Plant Association[1] | Areal Cover (Percent) | | | | Upland Vegetation Score | Total No. Upland Species | Wetland Vegetation Score | Total No. Wetland Species | Wetland Vegetation Designation | Wetland Vegetation Index |
|---|---|---|---|---|---|---|---|---|---|---|
| | UPL | FACU | FACW | OBL | | | | | | |
| PICO/EMNI | 6.0 | 14.3 | 44.5 | 10.8 | 26.3 | 17 | 66.1 | 36 | Wetland | 2.51 |
| TSHE-THPL/VACCI | 6.1 | 30.1 | 0.2 | 2.9 | 42.3 | 17 | 6.0 | 5 | Non-Wetland | 0.14 |
| TSHE-THPL/POMU | 6.2 | 29.9 | 1.5 | 0.8 | 42.3 | 14 | 3.1 | 4 | Non-Wetland | 0.07 |
| TSHE-THPL/VACCI/LYAM | 11.5 | 24.6 | 2.0 | 23.3 | 47.6 | 21 | 48.6 | 12 | Wetland | 1.02 |
| TSHE-THPL/VACCI-OPHO | 6.7 | 32.6 | 3.2 | 6.8 | 46.0 | 16 | 16.8 | 11 | Non-Wetland | 0.37 |
| TSHE-THPL/VACCI-GASH | 8.1 | 20.6 | 2.8 | 2.6 | 36.8 | 20 | 8.0 | 10 | Non-Wetland | 0.22 |
| TSHE-THPL/VACCI-GASH/LYAM | 14.1 | 18.0 | 2.7 | 15.7 | 46.2 | 17 | 34.1 | 9 | Non-Wetland | 0.74 |
| TSHE-THPL/GASH | 7.4 | 11.9 | 4.2 | 4.7 | 26.7 | 18 | 13.6 | 11 | Non-Wetland | 0.51 |

[1]Plant association codes are described in the appendix.

Table 3. Gradient of forest plant associations on the Ketchikan Area, Tongass National Forest. Associations are ranked from most hydric to least hydric, based on wetland indices (Table 2). Associations with indices greater than 1 are considered wetlands.

| Plant Association[1] | Wetland Vegetation Index | Plant Association[1] | Wetland Vegetation Index |
|---|---|---|---|
| MXD CON/GASH/LYAM | 2.56 | TSHE-THPL/OPHO/LYAM | 0.46 |
| PICO/EMNI | 2.51 | TSME/VACCI-CAME | 0.44 |
| MXD CON/GASH/FACR | 1.67 | MXD CON/VACCI | 0.42 |
| MXD CON/VACCI/FACR | 1.43 | TSHE-CHNO/VACCI | 0.41 |
| MXD CON/VACCI/LYAM | 1.39 | PISI/OPHO-LYAM | 0.39 |
| TSHE/VACCI/LYAM | 1.25 | TSHE-THPL/VACCI-OPHO | 0.37 |
| TSHE-THPL/GASH/LYAM | 1.06 | PISI/VACCI | 0.29 |
| TSHE-THPL/VACCI/LYAM | 1.02 | TSHE/VACCI/DRAU2 | 0.24 |
| TSHE-CHNO/VACCI/LYAM | 0.97 | TSHE-THPL/VACCI-GASH | 0.22 |
| MXD CON/VACCI-GASH | 0.78 | TSHE/VACCI-OPHO (HP) | 0.21 |
| TSME/VACCI-CLPY | 0.75 | TSHE/VACCI-OPHO (MP) | 0.21 |
| TSHE-THPL/VACCI-GASH/ LYAM | 0.74 | TSHE-THPL/VACCI | 0.14 |
| TSME/VACCI/VEVI | 0.73 | TSHE/OPHO | 0.13 |
| TSME/VACCI | 0.61 | TSHE/OPHO/POMU | 0.13 |
| PISI/VACCI/LYAM | 0.58 | PISI/OPHO-RUSP | 0.12 |
| MXD CON/GASH | 0.55 | PISI/OPHO | 0.11 |
| TSHE/VACCI | 0.54 | TSHE/VACCI/POMU | 0.09 |
| TSHE-THPL/GASH | 0.51 | PISI/VACCI-OPHO | 0.08 |
| PISI/ALNUS | 0.50 | TSHE-THPL/POMU | 0.07 |

[1]Names corresponding to plant association codes are listed in the Appendix.

**Table 4. Comparison of weighted average approaches (with and without facultative species) for selected forested plant associations on the Ketchikan Area, Tongass National Forest.**

| | | ----------Calculations without Facultative Species---------- | | | | | ---Calculation with Facultative Species--- | |
|---|---|---|---|---|---|---|---|---|
| Plant Association | Sample Size | Upland Vegetation Score | Wetland Vegetation Score | Wetland Vegetation Determination | Wetland Vegetation Index | Plot[1] Determination | Prevalence Index | Wetland Vegetation Determination |
| | n | | | | | | | |
| Mixed Conifer/Salal/ Skunk Cabbage | 6 | 19.0 | 48.7 | Wetland | 2.56 | 0.67 | 2.79 | Wetland |
| Shore Pine/Crowberry | 14 | 26.3 | 66.1 | Wetland | 2.51 | 1.00 | 2.68 | Wetland |
| Mixed Conifer/Salal/ Deer Cabbage | 20 | 19.0 | 47.4 | Wetland | 1.67 | 0.67 | 2.91 | Wetland |
| Mixed Conifer/ Blueberry/ Deer Cabbage | 27 | 40.9 | 58.6 | Wetland | 1.43 | 0.40 | 2.87 | Wetland |
| Mixed Conifer/ Blueberry/ Skunk Cabbage | 23 | 45.2 | 62.7 | Wetland | 1.39 | 0.78 | 2.91 | Wetland |
| Hemlock/Blueberry/ Skunk Cabbage | 39 | 37.5 | 46.9 | Wetland | 1.25 | 0.39 | 2.92 | Wetland |
| Hemlock-Redcedar/ Salal/ Skunk Cabbage | 8 | 14.5 | 15.4 | Wetland | 1.06 | 0.24 | 2.99 | Wetland |
| Hemlock-Redcedar/ Blueberry/ Skunk Cabbage | 34 | 47.6 | 48.6 | Wetland | 1.02 | 0.54 | 2.95 | Wetland |

[1]The fraction of plots considered hydric on an individual-plot, rather than average-plot basis. Plot determination values were the same for both approaches.

Table 5. List of wetland habitat types used in generation of GIS wetland maps.

| Forest Status[1] | Wetland Status[1] | Wetland Habitat Type Code | Habitat Type Name and Map Unit Description[2] |
|---|---|---|---|
| NF | W | AM | **ALPINE SHRUBLAND/EMERGENT MUSKEG**: Alpine communities with poorly-drained soils. Cowardin equivalent: combination of Palustrine Emergent Wetland and Palustrine Scrub-Shrub Wetland. |
| NF | W | BW | **SCRUB-SHRUB ALDER/WILLOW**: Shrub community. Trees less than 25 feet high. Primarily in Yakutat. Cowardin equivalent: Riverine, Lower/Upper Perennial, Emergent Wetland. |
| NF/F | W | SE | **SCRUB-SHRUB EVERGREEN/MUSKEG**: Bog vegetation, but not primarily sedges or moss. When conifers are present they are less than 25 feet in height. Cowardin equivalent: Palustrine Scrub-Shrub Wetland. |
| NF | W | MT | **EMERGENT TALL SEDGE MUSKEG**: Muskeg communities dominated by tall sedges. Cowardin equivalent: Palustrine Emergent Wetland. |
| NF | W | MS | **EMERGENT SHORT SEDGE MUSKEG**: Muskeg communities dominated by short sedges. Cowardin equivalent: Palustrine Emergent Wetland. |
| NF | W | MP | **MOSS MUSKEG (SPHAGNUM PEAT MUSKEG)**: Muskegs characterized by deep, very poorly-drained accumulation of sphagnum moss. Cowardin equivalent: Palustrine Emergent Wetland. |
| NF | W | M | **ESTUARINE SUBTIDAL MUDFLAT**: Code is a channel type designation. Cowardin equivalent: Estuarine, Subtidal, Unconsolidated bottom. |
| NF | W | E | **ESTUARINE EMERGENT**: Primarily sedge communities. Cowardin equivalent: All classes in Estuarine, Intertidal. |
| F | W | FW | **FORESTED WETLAND**: Forested wetland plant associations. Cowardin equivalent: Palustrine Forested Wetland. |
| F | NW | FNW | **FORESTED NON-WETLAND**: Also includes non-wetland portions of riparian zones. Cowardin equivalent: Upland. |
| NF | W | W | **LAKES AND PONDS**: Cowardin equivalent: All those in Lacustrine system. |

[1]Codes: F=Forest; NF=Non-Forest; W=Wetland; NW=Non-wetland; and MX=Wetland/Non-wetland complex.

[2]The equivalent Cowardin designations are from Cowardin et al. (1979).

Table 5 (Continued).

| Forest Status | Wetland Status | Wetland Habitat Type Code | Habitat Type Name and Map Unit Description |
|---|---|---|---|
| | | | **FORESTED WETLAND/FORESTED NON-WETLAND COMPLEXES** |
| F | MX | FIC | •Complex of hydric and non-hydric types, non-hydric component greater than 50% |
| F | MX | FI | •Complex of hydric and non-hydric types, composition of each is 50% |
| F | MX | FIW | •Complex of hydric and non-hydric types, hydric component greater than 50% |
| | | | **FORESTED WETLAND/EMERGENT SEDGE COMPLEX** |
| NF/F | W | FES | •Less than 50% of map unit is forested. |
| F/NF | W | FEF | •At least 50% of map unit is forested. |
| | | | **FORESTED WETLAND/MOSS (SPHAGNUM) MUSKEG COMPLEX** |
| NF/F | W | FSS | •Less than 50% of map unit is forested. |
| F/NF | W | FMS | •At least 50% of map unit is forested. |
| | | | **FORESTED WETLAND/NON-FOREST NON-WETLAND COMPLEX** |
| NF/F | MX | FIH | •Less than 50% of map unit is forested. |
| F/NF | MX | FIA | •At least 50% of map unit is forested. |
| | | | **FORESTED WETLAND-ALPINE SHRUBLAND/EMERGENT MUSKEG COMPLEX** |
| F/F | W | AMM | •Less than 50% of map unit is forested. |
| F/NF | W | AMI | •At least 50% of map unit is forested. |
| | | | **FORESTED SCRUB-SHRUB EVERGREEN/EMERGENT SEDGE COMPLEX** |
| NF/F | W | SES | •Less than 50% of map unit is forested scrub-shrub evergreen. |
| F/NF | W | SEC | •At least 50% of map unit is forested scrub-shrub evergreen. |
| | | | **FORESTED NON-WETLAND/EMERGENT SEDGE COMPLEX** |
| NF/F | MX | FNS | •Less than 50% of map unit is forested. |
| F/NF | MX | FNE | •At least 50% of map unit is forested. |
| | | | **FORESTED NON-WETLAND/MOSS COMPLEX** |
| NF/F | MX | FSU | •Less than 50% of map unit is forested. |
| F/NF | MX | FSW | •At least 50% of map unit is forested. |

Table 5 (Continued).

| Forest Status | Wetland Status | Wetland Habitat Type Code | Habitat Type Name and Map Unit Description |
|---|---|---|---|
| | | | **ALPINE DWARF EVERGREEN/ALPINE SHRUBLAND COMPLEX** |
| NF | MX | ADD | •Less than 50% of unit is alpine dwarf evergreen. |
| NF | MX | ADI | •At least 50% of unit is alpine dwarf evergreen. |
| | | | **ALPINE SHRUBLAND/NON-WETLAND NON-FOREST COMPLEX** |
| NF | MX | AMN | •Less than 50% of unit is alpine shrubland. |
| NF | MX | AMX | •At least 50% of unit is alpine shrubland. |
| NF | W | AMS | Complex of tall sedge muskeg and alpine shrubland muskeg. |

By relating areas of soil map units in the GIS to wetland habitat classifications, areas of wetland classes can be generated. This has proven to be a powerful planning tool. As an example, information for the long term sale area on northern Prince of Wales Island is presented in Table 6. Areas affected by planned logging and road-building can be determined and mitigation planned, if appropriate. The maps can also be used in making decisions on logging unit location.

**Table 6. Wetland area (acreages) affected by the long-term timber sale area for the 1989-1994 operating period. Figures were derived by relating wetland habitat codes to soil map units of known area.[1]**

| Class | ---Acres--- Total Acres | ------------Wetland Areas Affected By---------- Proposed Timber Harvest | Proposed Use For Roads |
|---|---|---|---|
| | acres (%)[2] | acres (%)[2] | acres (%)[2] |
| Non-Wetlands | 375 212 (45) | 18 110 (2) | 1 225 (<1) |
| Forested Wetlands | 268 417 (32) | 9 962 (1) | 791 (<1) |
| Muskegs | 196 220 (24) | 3 825 (0.5) | 319 (<1) |
| Estuaries | 233 (<1) | 0 (0) | 0 (<1) |
| Total Wetlands | 458 870 (55) | 13 787 (2) | 1 110 (<1) |
| Total Sale Area | 834 082 (100) | 45 684 (5) | 2 335 (<1) |

[1]Acres expressed as a percentage of the total area are shown in parentheses.
[2]Information prepared by Tom Bobbe, Patti Cullen, and Dennis Landwehr, USDA Forest Service, Ketchikan.

## Conclusion

Development of wetland maps and reports by a geographic information system using soils inventory and related plant association data is an effective tool in forest planning. Resulting maps agreed substantially with National Wetland Inventory maps, but detail varied somewhat due to differing objectives and procedures. The soil and vegetation data are sufficient for the needs of the Tongass Land Management Plan Revision, at least for forest communities. Further analysis may be necessary to refine the soils-plant association relationship to address wetland issues, concerns and opportunities at the project level.

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## Appendix

Full names of forest plant association codes used in Tables 2 and 3.

| Code | Scientific Name | Common Name |
|---|---|---|
| **TSHE Series** | **Tsuga heterophylla** | **Western hemlock** |
| TSHE/VACCI | Vaccinium spp. | blueberry |
| TSHE/VACCI/DRAU | Vaccinium spp.<br>Dryopteris austriaca | blueberry<br>spinulose shield-fern |
| TSHE/VACCI/LYAM | Vaccinium spp.<br>Lysichitum americanum | blueberry<br>skunk cabbage |
| TSHE/VACCI-OPHO (HP) | Vaccinium spp.<br>Oplopanax horridium | blueberry<br>devil's club |
| TSHE/VACCI-OPHO (MP) | Vaccinium spp.<br>Oplopanax horridium | blueberry<br>devil's club |
| TSHE/OPHO | Oplopanax horridium | devil's club |
| TSHE/OPHO/LYAM | Oplopanax horridium<br>Lysichitum americanum | devil's club<br>skunk cabbage |
| TSHE/OPHO/POMU | Oplopanax horridum<br>Polystichum munitum | devil's club<br>sword fern |
| **TSHE-CHNO Series** | **Tsuga heterophylla**<br>**Chamecyparis nootkatensis** | **Western hemlock**<br>**Alaska cedar** |
| TSHE-CHNO/VACCI | Vaccinium spp. | blueberry |
| TSHE-CHNO/VACCI/LYAM | Vaccinium spp.<br>Lysichitum americanum | blueberry<br>skunk cabbage |
| TSHE-CHNO/VACCI-OPHO | Vaccinium spp<br>Oplopanax horridum | blueberry<br>devil's club |
| **PISI Series** | **Picea sitchensis** | **Sitka spruce** |
| PISI/VACCI | Vaccinium spp. | blueberry |
| PISI/VACCI-OPHO | Vaccinium spp.<br>Oplopanax horridium | blueberry<br>devil's club |
| PISI/OPHO | Oplopanax | devil's club |
| PISI/OPHO/CIAL | Oplopanax horridium<br>Circea alpina | devil's club<br>enchanter's nightshade |

| | | |
|---|---|---|
| PISI/OPHO/LYAM | Oplopanax horridium<br>Lysichitum americanum | devil's club<br>skunk cabbage |
| PISI/ALNUS | Alnus spp. | alder |
| PISI/CANU | Calamagrostis nutkatensis | Pacific reedgrass |
| PISI/VACCI/LYAM | Vaccinium<br>Lysichitum americanum | blueberry<br>skunk cabbage |
| **MIXED CONIFER Series** | **Mixed Conifer** | **Mixed Conifer** |
| MXD CON/VACCI | Vaccinium spp. | blueberry |
| MXD CON/VACCI/LYAM | Vaccinium spp.<br>Lysichitum americanum | blueberry<br>skunk cabbage |
| MXD CON/VACCI/FACR | Vaccinium spp.<br>Fauria crista-galli | blueberry<br>deer cabbage |
| MXD CON/LYAM-ATFI | Lysichitum americanum<br>Athyrium filix-femina | skunk cabbage<br>lady fern |
| MXD CON/GASH/FACR | Gaultheria shallon<br>Fauria crista-galli | salal<br>deer cabbage |
| MXD CON/VACCI-GASH/VEVI | Vaccinium spp.<br>Gaultheria shallon<br>Veratrum viride | blueberry<br>salal<br>false hellebore |
| MXD CON/VACCI-GASH | Vaccinium spp<br>Gaultheria shallon | blueberry<br>salal |
| MXD CON/GASH/LYAM | Gaultheria shallon<br>Lysichitum americanum | salal<br>skunk cabbage |
| MXD CON/VACCI-GASH/LYAM | Vaccinium spp.<br>Gaultheria shallon<br>Lysichitum americanum | blueberry<br>salal<br>skunk cabbage |
| MXD CON/VACCI-GASH/LYAM | Vaccinium spp.<br>Gaultheria shallon<br>Lysichitum americanum | blueberry<br>salal<br>skunk cabbage |
| MXD CON/GASH | Gaultheria shallon | salal |
| **TSME Series** | **Tsuga mertensiana** | **Mountain hemlock** |
| TSME/VACCI | Vaccinium spp. | blueberry |

| | | |
|---|---|---|
| TSME/VACCI-CLPY | Vaccinium spp.<br>Cladothamnus pyrolaeflorus | blueberry<br>copper bush |
| TSME/VACCI-CAME | Vaccinium spp.<br>Cassiope mertensiana | blueberry<br>Mertens cassiope |
| TSME/VACCI/VEVI | Vaccinium spp.<br>Veratrum viride | blueberry<br>false hellebore |
| **PICO Series** | **Pinus contorta** | **Shore Pine** |
| PICO/EMNI | Empetrum nigrum | crowberry |
| **TSHE-THPL Series** | **Tsuga heterophylla-Thuja pli-cata** | |
| TSHE-THPL/VACCI | Vaccinium spp | blueberry |
| TSHE-THPL/POMU | Polystichum munitum | swordfern |
| TSHE-THPL/VACCI/LYAM | Vaccinium spp<br>Lysichitum americanum | blueberry<br>skunk cabbage |
| TSHE-THPL/OPHO/POMU | Oplopanax horridum<br>Polystichum munitum | devil's club<br>swordfern |
| TSHE-THPL/VACCI-OPHO | Vaccinium spp<br>Oplopanax horridum | blueberry<br>devil's club |
| TSHE-THPL/VACCI-GASH | Vaccinium spp<br>Gaultheria shallon | blueberry<br>salal |
| TSHE-THPL/VACCI-GASH/LYAM | Vaccinium spp<br>Gaultheria shallon<br>Lysichiton americanum | blueberry<br>salal<br>skunk cabbage |
| TSHE-THPL/GASH-LYAM | Gaultheria shallon<br>Lysichitum americanum | salal<br>skunk cabbage |
| TSHE-THPL/GASH | Gaultheria shallon | salal |
| TSHE-THPL/OPHO/LYAM | Oplopanax horridum<br>Lysichitum americanum | devil's club<br>skunk cabbage |

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Prepared by Jon Martin, USDA Forest Service, Sitka.

# A Proposed Streamside Riparian Mapping System for the Tongass National Forest

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***Abstract.*** The Tongass National Forest, Alaska Region of the USDA Forest Service requires a means to inventory and assign management prescriptions to areas adjacent to streams. An integrated approach to mapping riparian ecosystems for forest planning, inventory and analysis is presented. A hierarchical approach which incorporates geomorphology, hydrology, soils and climax plant communities (Plant Associations) as the primary mapping features is used to map, inventory, catalogue, evaluate, and manage riparian zones for multiple sustained uses. We explain working definitions and concepts of riparian ecosystems, outline processes to integrate existing data and inventories into a riparian classification, outline the mapping hierarchy, describe major levels in the heirarchy, and discuss the utility of a riparian classification and mapping system.

Riparian is defined by Webster's dictionary (Editorial Staff, 1977) as relating to or living or located on the bank of a natural watercourse or sometimes of a lake or a tidewater. Streamside zones with landforms shaped by fluvial processes, soils developed in part by flooding processes of erosion and or deposition, and plants requiring free and unbound water are referred to as riparian ecosystems. Riparian ecosystems are recognized as some of the most diverse and productive landscapes in southeast Alaska. Their diversity results from variability in flooding disturbance cycles, ground water regimes, chemical and physical weathering, material transport and deposition, and multiple cumulative inputs received from higher elevation landscapes in watersheds. Fluvial geomorphic processes and cycles of disturbance and rejuvenation maintain the diversity of these zones.

*Riparian Resources*

Southeast Alaska riparian ecosystems contain a variety of plant communities, from gravel/forb river bottoms to a variety of shrubland types and tree dominated plant communities. Sitka spruce is the commercial timber species typically associated with the most stable riparian zones. They reach their highest basal area and volume within the riparian zone. The streams are renowned producers of five species of salmon and three trout species. Many wildlife species utilize the streamside zone as water sources, feeding zones, transportation corridors and bedding and nesting sites. Riparian zones are extremely important habitat for brown bear, black bear, wolves, eagles, ducks, geese, trumpeter swan, beaver, martin, and mink. Human demands on the riparian ecosystem arise from its value to commercial, subsistence and sport fisheries, the timber industry and people seeking a variety of recreational opportunities.

Riparian ecosystems occur on small portions of the landscape. An analysis of watersheds on northeast Chichagof Island revealed aquatic and riparian ecosystems ranged from 2% to 7% of total watershed areas. Because these ecosystems are valued producers of many resources over a disproportionately small segment of the watershed, conflicts between many different riparian resource users are common. With the ever increasing demands on riparian resources these conflicts can be expected to increase.

*Need for a Riparian Mapping System*

The Tongass National Forest has recognized a growing concern over management of the streamside zone. As required by the National Forest Management Act (NFMA), National Forests must produce a Forest Plan every 10 to 15 years. The Tongass National Forest is currently revising its Forest Plan, the Tongass Land Management Plan (TLMP). One purpose of the Riparian classification is to address issues raised in the Forest Planning process. Prior to the analysis process for the TLMP revision, fish and wildlife managers expressed the need for an ecologically sound mapping system from which they can inventory fish and wildlife habitats, assess fish and wildlife potentials and enhancement opportunities, and design prescriptions for managing the fisheries and wildlife resource of the Tongass National Forest. Likewise, foresters can utilize the riparian mapping system in the TLMP revision to assess opportunities for timber harvest and as a decision tool in setting buffer zones along stream systems.

In southeast Alaska, due to the rich diversity of riparian ecosystems and the gradation of riparian characteristics into the surrounding upland, it is often difficult to discern the boundary between riparian and non-riparian landscapes. Identifying the difference between riparian and non-riparian landscapes and then stratify-

ing riparian landscapes as to their multi-varied uses will help Tongass National Forest land managers plan efficient, sound use of these highly productive yet sensitive ecosystems. This paper describes a process for inventorying riparian ecosystems. It describes a riparian classification and its hierarchy and illustrates the Tongass National Forest approach to mapping and evaluating management options for streamside riparian ecosystems. Other types of riparian ecosystems; estuary, shoreline, abandoned lake basins, marshes, bogs, and wetlands not associated with stream systems are beyond the scope of this paper and will not be discussed herein.

It has been suggested that any viable classification and mapping scheme for the streamside zone required an integrated inventory of three components:

1. Streams.
2. Geomorphic Surfaces.
3. Plant Communities.[1]

The Tongass National Forest has mapped streams in its Channel Type Inventory and has mapped geomorphic surface and plant communities in its Soil/ Plant association classification and inventory. Participants from the three administrative areas of the Tongass National Forest held a workshop in November of 1986 to devise a riparian classification hierarchy and mapping system.

## Setting

*Riparian Vegetation*

Vegetation of riparian ecosystems on the Tongass N.F. are mosaics of shrub dominated plant communities and coniferous forest. Flooding events create a complex of successional patterns from rapidly evolving early seral stages to old growth forest stands subject to slower changes. Seral communities perpetuated by disturbance occur on the more active fluvial surfaces having predictable disturbance regimes. On the less active fluvial surfaces climax plant communities may become established. On relatively stable sites, often only minor changes occur in the old growth forest vegetation and patterns.

Forested riparian plant communities contain large, widely spaced Sitka spruce in the overstory and devil's club, salmonberry, currant and alder in the understory. Sitka spruce Plant Associations on stable floodplains are most often two tiered stands with western hemlock occurring in the lower tier. Mixed spruce and red alder stands are common on floodplains that receive a moderate amount of flooding disturbance. Alder, salmonberry, currant and devil's club shrub communities occur in narrow bands along most streams and in large patches on the extremely active floodplains. Tall sedge meadow plant communities occur in some backwater areas in large flat valleys associated with beaver impoundments and old glacial lake beds. Deciduous or mixed stands of coniferous and deciduous forests are common along the youthful surfaces of the large mainland glacial river systems and in Yakutat.

*Soil Development on Riparian Landscapes*

The soils on these sites are most often well drained stratified sands, silts and gravels. The frequency and magnitude of flooding and the level and amount of fluctuation in the water table are controlled by geomorphology, watershed size, location in a watershed, microsite characteristics and local rainfall patterns. Flooding events disturb the soil and vegetation to varying degrees. During large magnitude events, sites are often eroded to bare mineral soil completely devoid of vegetation. Frequently disturbed floodplain sites tend to be dominated by herbaceous and shrub plant communities. These sites are continually "set back" successionally, hence never achieving climax vegetation. Instead these sites remain in shrub dominated plant communities. Riparian sites which are flooded by frequent low magnitude events tend to be dominated by Sitka spruce in the overstory with disturbance shrubs in the understorys. Riparian sites which are flooded by infrequent, low magnitude events are also dominated by spruce in the overstory, however blueberry dominates the understory. Adjacent upland sites typically grade into western hemlock dominated forest with blueberry dominated understories.

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[1]Concurrent with the rising interest in the Tongass National Forest about riparian ecosystem management, Ecologists of the Pacific Northwest Region of the Forest Service held a workshop that attempted to develop a riparian ecosystem classification. The outcome of that meeting was a unanimous agreement that any viable classification and mapping scheme for the streamside zone required an integrated inventory of plant community, gemorphic surface and stream mapping system. Letter to Forest Supervisor, Tongass National Forest from Ross, R.N. Director of range and Watershed Management, R-6. Classification of Riparian Habitats, 2060. 10/16/86.

**Objectives**

In devising a riparian mapping system five major objectives were listed:

1. *To establish definitions* used in the riparian classification.
2. *To combine existing classifications and inventories* into a hierachical framework for classification, mapping, and management.
3. *To create, differentiate and describe levels of the hierarchy.*
4. *To provide guidelines for identifying and mapping* the riparian ecosystem.
5. *Assess future needs* to establish a riparian zone hierarchy as a tool for management.

**Definitions**

*Ecosystem* - Ecosystem is defined as a complete interacting system of organisms and their environment[1]. The exact boundaries of an ecosystem is somewhat arbitrary because each is interconnected with other ecosystems as components of larger systems (Gabriel and Talbot, 1984). For example, since the aquatic ecosystem is so closely allied with the riparian ecosystem, it may become difficult to separate them. Likewise, the terrestrial ecosystem interacts with both of these systems.

The aquatic, terrestrial and riparian ecosystems are defined in the Forest Service Manual[2] as:

*Aquatic Ecosystems* - The stream channel, lake bed or estuary, water, biotic communities, and the habitat features contained therein.

*Terrestrial Ecosystems* - All other ecosystems not included in the aquatic or riparian ecosystem definitions.

*Riparian Ecosystems* - A riparian ecosystem is a transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; identified by soil characteristics or distinctive vegetation communities that require free or unbound water.

Riparian ecosystems occur on land which is transitional between the aquatic ecosystem and the terrestrial ecosystem. They are identified by vegetation that require free or unbound water, or conditions that are more moist than normal (Franklin and Dyrness, 1973).

*Riparian-Aquatic Zone* - Riparian-Aquatic Zone (RAZ) is comprised of the total area occupied by riparian and aquatic ecosystems in a watershed. The RAZ is a land management concept adopted by the Alaska Region of the USDA Forest Service designed to represent the riparian ecosystem. On streams where the riparian vegetation is sparse to absent, the RAZ is hard to identify. This is particularly true on incised streams with long steep sideslopes (Fig. 1). In these "V-notch" incised streams the adjacent terrestrial ecosystem have a large impact on the aquatic ecosystem through soil movement and/or large organic debris input. Therefore, these stream adjacent sideslopes are included in the RAZ.

*Riparian Areas* - The Forest Service[2] identifies the riparian area as the basic unit to manage riparian dependent resources. The Forest Service manual defines this management unit as follows: - Geographically defineable areas with distinctive resource values and characteristics that are comprised of the aquatic and riparian ecosystem. Riparian Area's are mapped polygons representing unique riparian ecosystem components within a RAZ.

*Riparian Site* - The Riparian Site is the field observation point comprised of a segment of a Channel Type, a single soil series and a Plant Association used in compiling primary data bases for analysis and interpretation. Information collected at Riparian Sites is summarized to describe the Riparian Area for which they were collected.

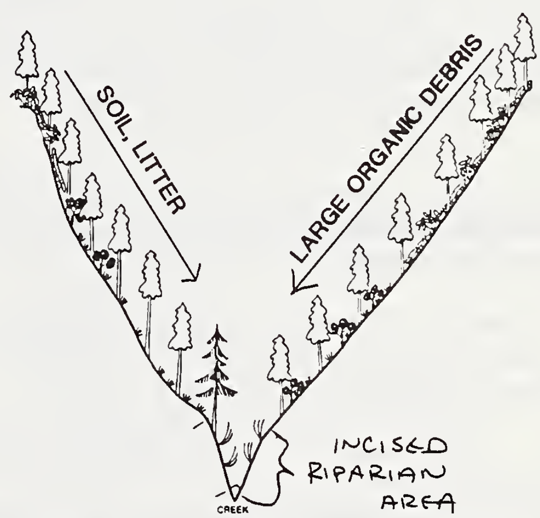


**Figure 1. An incised stream Riparian Area cross-section, one-way system.**

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[1]Forest Service Handbook on Ecosystem Classification, Interpretation and Application. USDA-Forest Service. 1983. FSH 2060.

[2]Forest Service Manual on Riparian Area management. USDA-Forest Service. 1986. FSM 2526.

## Inventory Integration

The Tongass National Forest Riparian Mapping System was developed from the integration of existing data bases and inventories. The Channel Typing, Soils and Plant Association Classifications and Inventories were used in the Geographical Information System (GIS) to generate RAZ and Riparian Area maps. The GIS components include: a Watershed Layer which delineates watershed boundaries; a Channel Type Layer which contains the stream inventory; and a Soil/Plant Association Layer, which contain the Landform, Soil and Plant Association inventory maps and data.

The Channel Type Inventory is a stream classification and mapping system developed on the Tongass National Forest and expanded to include all of Southeast Alaska. Stream channel components used to differentiate Channel Types are: channel gradient, channel width, incision depth, sideslope length and angle, substrate type, channel depth, and source waters. Channel Types describe the aquatic ecosystem conditions that strongly influence riparian ecosystem distribution and development. A list of Channel Types for southeast Alaska is presented in Table 1.

Landform mapping, derived from the Soil/Plant Association inventories, is used to identify geographic areas predominately influenced by fluvial processes. Landforms with distinctly fluvial process are floodplains, alluvial fans, dissected footslopes and valley gorges. Landform maps delineate the maximum width the Riparian-Aquatic Zone (RAZ) may occupy.

**Table 1. Stream Channel Type classification used in the Riparian Mapping System hierarchy for the Tongass National Forest [1,2]**

### INCISED, CONTAINED STREAM CHANNELS

*Moderate to High gradient channels.*

A1 - Very deeply incised, high gradient mountain slope channel.
A2 - Deeply incised, high gradient mountain slope/upper valley channel.
A4 - Shallowly incised, very high gradient mountain slope channel.
A5 - Deeply incised, high gradient mountain slope (moderate to short slopes).
A6 - Shallowly incised, high gradient mountain slope channel.
A7 - Shallowly incised, high gradient, foot slope channel.
B7 - Deeply incised gorge channel, moderate gradient.
D2 - Deeply incised, high gradient mountain slope/upper valley channel, glacial water source.
D7 - Deeply incised gorge channel, moderate gradient, glacial water source.

*Low to Moderate gradient channels*

B4 - Shallowly incised, moderate gradient transitional foot slope/lowland channel.
B6 - Moderately incised, moderate gradient transitional foot slope lowland channel.
C2 - Shallow to moderately incised. valley/lowland channel.
C5 - Moderately incised, narrow valley channel.

### UNCONTAINED ALLUVIAL STREAM CHANNEL TYPES

A3 - High gradient alluvial/colluvial fan.
B1 - Low gradient lowland/valley floodplain channel.
B2 - Moderate gradient foot slope channel.
B3 - Moderate gradient valley floodplain channel.
B5 - Low gradient alluvial fan.
B8 - Narrow, low gradient, uplifted estuary channel.
C1 - Low gradient floodplain channel.
C3 - Large floodplain channel.
C4 - Low gradient coastal beach dune channel.
C6 - Low gradient, large uplifted estuary channel.
D3 - Moderate gradient valley floodplain channel, glacial water source.
D3 - Large floodplain channel, glacial water source.
D5 - Braided, low gradient, glacial channel.
D6 - High gradient alluvial/colluvial fan, glacial water source.

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[1]Channel Type Taxonomic Legend, USDA Forest Service Region 10. FSH 2609.24-22. Aquatic Habitat Management Handbook, March 1988 Draft.

[2]E & L Channel Types typically associated with wetland ecosystems are not included within this classification framework.

Soils and Plant Association maps are used to stratify the RAZ into Riparian Areas. The degree of development within a soil, its weathering profile characteristics and the kinds and sizes of alluvial parent materials provide a relative indication of frequency and intensity of flooding events. Plant communities are prime indicators of flooding disturbance and provide data as to site potential, site productivity and habitat characteristics. The soils which are associated with the RAZ are listed in table 2. A list of riparian plant communities are presented in table 3.

### Riparian Classification and Mapping Hierarchy

Each level of the hierarchy is unique from other levels in that it provides specific information which can be easily understood by a variety of users, and is useful for management. Mapping criteria are based on ecological relationships rather than management constraints. The use of a hierarchical approach in the development of riparian maps ensures flexibility in delineation and identification of riparian ecosystems. A hierarchical framework for the Riparian Mapping System makes general data available at higher levels in the hierarchy for broad level planning where greater variability and general interpretations are acceptable. At lower levels in the hierarchy more detailed information is provided for site specific interpretations are on projects such as timber layout design, road location, fish enhancement projects and silvicultural prescriptions.

The hierarchy is illustrated in Figure 2. There are four levels of the Riparian Mapping System. Watershed boundaries are delineated at the broadest level,the Watersheds layer. The next level, the *RAZ* delineates smaller geographic units within watersheds (floodplains, alluvial fans, dissected footslopes, valley gorges and upland stream channels with riparian resources absent) that encompass riparian ecosystems and those terrestrial ecosytems that directly influence stream channels. The RAZ delineates the perimeter of land containing riparian ecosystems within a watershed. The *Riparian Area* is the third level of the hierarchy. The Riparian Area is mapped by and comprised of a channel type and complexes of soils and Plant Associations. It stratifies the RAZ into smaller units that have detailed information needed to design and implement forest management project planning. The lowest level of the classification is the *Riparian Site*. The Riparian Site consists of a plant association and a soil next to a particular channel type. This level of the hierarchy has a primary function as a data observation point for research, inventory and monitoring.

*Level I - Watersheds*

The Watershed GIS data layer locates and identifies watershed boundaries, calculates watershed area, and is used in estimating annual precipitation and computing water budgets.

**Table 2. General characteristics of soils commonly found in Riparian ecosystems on the Tongass N.F., Southeast Alaska.**

**Tuxekan** - (coarse-loamy over sandy or sandy-skeletal, mixed Humic Cryorthods) very deep, well drained, well developed soils formed on upper floodplain terraces and fans that are seldom flooded.

**Tonowek** - (coarse-loamy over sandy or sandy-skeletal, mixed non-acid Typic Cryofluvents) very deep, well drained, weakly developed soils formed on active floodplains and lower stream terraces that are intermittently to frequently flooded .

**Tonowek, sandy phase** - (sandy over sandy skeletal mixed Typic Cryorthents) very deep, well drained, weakly developed soils formed on active floodplains and lower stream terraces that are intermittently to frequently flooded.

**Kasianna, flooded phase** - (sandy-skeletal, mixed Histic Cryaquepts)poorly drained, weakly developed soils with intermixed strata of organic accumulations.

**Mitkof, flooded phase** (mixed Placic Haplaquods) somewhat poorly drained, well developed eroded till soils on floodplains.

**Bradfield** - (sandy, mixed Aquic Cryofluvents) somewhat poorly drained, weakly developed, fine sandy, depositional soils.

**Bradfield, gravelly phase** - (sandy over sandy skeletal, mixed Typic Cryaquents) poorly drained, weakly developed, fine sandy depositional soils with intermixed gravel strata.

**Riverwash** - misc.land unit (SA)

**Table 3. Streamside riparian Plant Associations and plant communities on the Tongass N.F., Southeast Alaska (Martin et al., 1985; Viereck et al., 1986, for the non-forest commmunities).**

**Gravel/Herbaceous** - Occurs below full bank and above water line and also occurs on frequently flooded, intermittent stream beds.

**Herbaceous** - Typically a narrow fringe of grass, forb and fern communities that occur either above bank full but below the shrub communities. Also may be a rather broad type along some streams.

**Scrub** - Shrub dominated communities. Typically Sitka alder, salmonberry, currant and devil's club dominated types between the upper bank full and the coniferous forest.

**Broadleaf Forest** - Red alder and cottonwood dominated communities between upper bank and coniferous forest.

**Sitka Spruce Series** - Plant communities dominated by Sitka spruce.

*Sitka Spruce/Alder* (PISI/ALNUS) - Spruce and alder dominated plant association. Frequently flooded.

*Sitka Spruce/Devil's Club* (PISI/OPHO) - Spruce and devil's club dominated plant association. Frequently flooded.

*Sitka Spruce/Devil's Club/Skunk Cabbage* (PISI/OPHO/LYAM) - Spruce, devil's club and skunk cabbage dominated forest. Frequently flooded.

*Sitka Spruce/Devil's Club-Blueberry* (PISI/OPHO/VACCI) - Spruce, devil's club and blueberry dominated forest.

*Sitka Spruce/Blueberry/Skunk Cabbage* (PISI/VACCI/LYAM) - Spruce, blueberry and skunk cabbage dominated forest. Most common on the Ketchikan Area.

*Sitka Spruce/Blueberry* (PISI/VACCI) - Spruce and blueberry dominated forest.

*Sitka Spruce-Cottonwood/Alder* (PISI-POTR/ALNUS) - Spruce and Cottonwood dominated open forest. Alder is a major component. Most common in glacially fed systems.

*Sitka Spruce-Cottonwood/Willow* (PISI-POTR/SALIX) - Spruce and Cottonwood dominated open forest. Willow is a major component. Most common the north Tongass.

*Sitka Spruce-Cottonwood/Devils club* (PISI-POTR/OPHO) - Spruce and Cottonwood dominated open forest. Devils club occupies the understory. Most common in glacially fed systems.

*Sitka Spruce-Cottonwood/Blueberry-Devils club* (PISI-POTR/VACCI-ALNUS) - Spruce and Cottonwood dominated open forest. Blueberry and Devils club dominate the understory. Most common in glacially fed systems.

*Level II - Riparian-Aquatic Zone (RAZ)*

The RAZ delineates the boundary between the aquatic-riparian ecosystems and the surrounding terrestrial landscape. The RAZ is the aggregation of all Riparian Areas within a watershed. It is a basic tool for Forest level planning for transportation and timber harvest analysis. The RAZ is mapped by overlaying the Soil/Plant Association Layer which delineates landform, with the Channel Type Layer and the Watershed Layer. Riparian Landforms and Channel Types are used to define the maximum extent of the riparian ecosystem. Riparian Landforms map the body of the RAZ which includes all riparian dependent resources of the streamside zone. Channel Types that are not associated with Riparian Landforms map the extended arterial network of upland stream systems (Fig. 3). They are aquatic ecosystems without associated riparian ecosystems, but are significantly influenced by the surrounding terrestrial ecosystems.

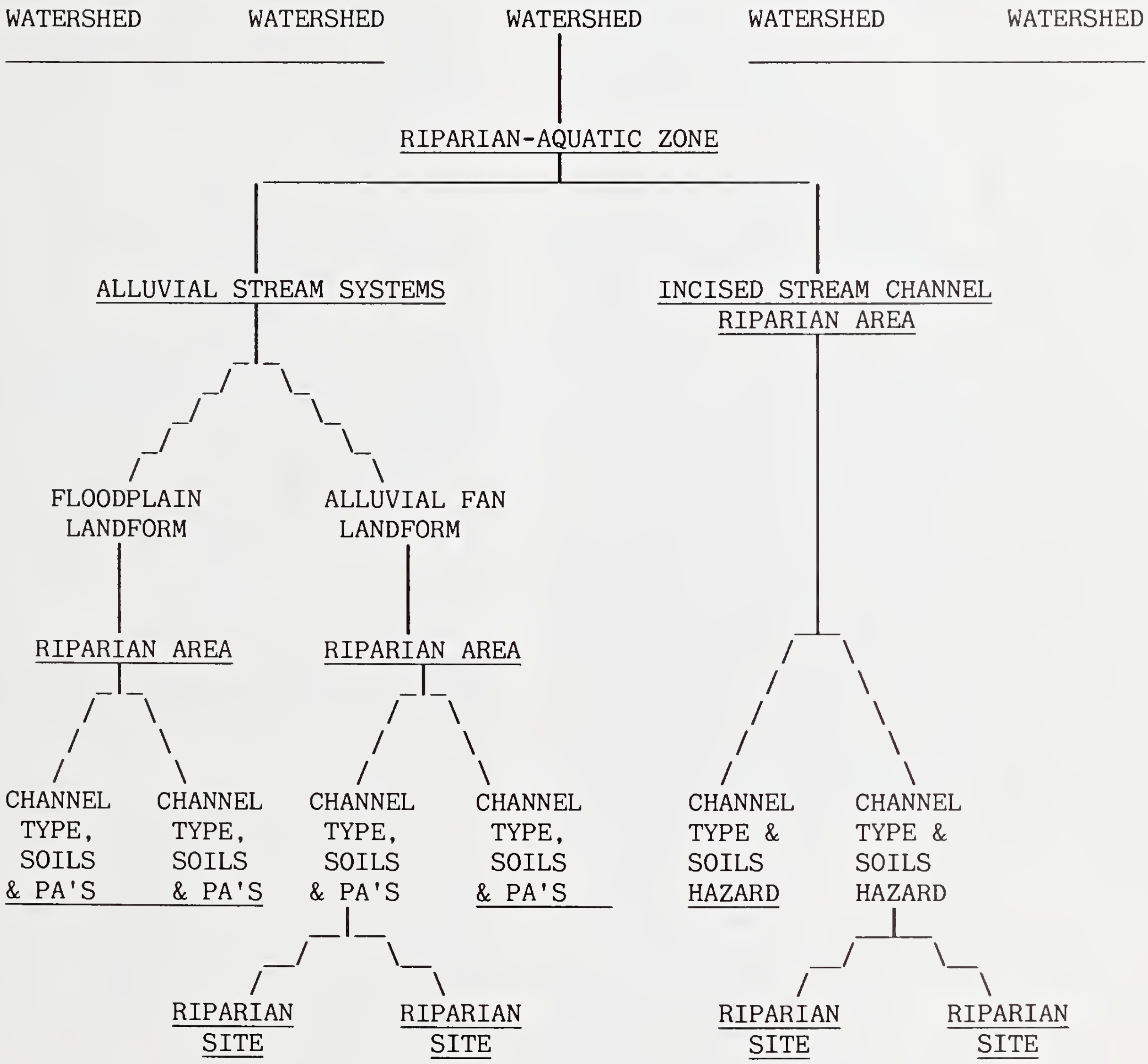


**Figure 2. Riparian Mapping System Hierarchy.**

*Landforms*

Landform was mapped as part of the Soil/Plant Association inventory[1]; Riparian Landforms are delineated using the Soil/Plant Association GIS layer. Riparian Landforms are shaped by streams or fluvial processes. They include floodplains, alluvial fans, and fluvially dissected footslopes. Landform groups riparian soils and plant communities into large units. Landforms often encompass relatively large areas and contain a wide range of riparian plant communities and soils. These Riparian Landforms also contain inclusions of plant communities and soils which are not technically riparian.

Floodplain landforms have extensive over-bank flooding. Adjacent stream channels are typically low gradient third or fourth order streams with high volume waterflow and high magnitude flood events. Slope gradients are 0% to 5%; soils are stratified gravels, sands and silts; and sites are occupied by riparian dependent plant species[2]. Shallow alluvial aquifers and high water tables are common characteristics in these landforms.

Alluvial fan and dissected footslope landforms are composed of coarse textured and gravelly soils of mixed alluvial and colluvial origin. Slope gradients vary between 0% to 35%, the former occurring on the fan toe, while the latter occurs at the slope break where the fan joins the adjacent mountain or hillslope. High energy, low to moderate magnitude stream flows are characteristic of streams associated with this landform. Episodic overbank flooding is a common fluvial process on these landforms. These events deliver high volumes of coarse sediment which quickly deposit in the stream bed, in the channel banks and often across large areas adjacent to the stream. Channel migration or abandonment often occurs during these events. The numerous, low order, intermittent stream channels also occur throughout these landforms. Riparian plant communities are frequently discontinuous and often interspersed with plant communities which are not riparian in nature. Plant Associations in the Sitka Spruce Series occur along the actively flooded areas and on sites which have high seasonal water flows. Western hemlock plant communities and others may occur on elevated sites not subject to flooding or high subsurface water tables. The riparian communities are generally wider along the toe of the fan and get progressively narrower upslope.


**Figure 3. A Riparian-Aquatic Zone (RAZ) map of northeast Chichagof Island, Southeast Alaska.**

*Channel Types*

The Channel Type classification provides the basis for classifying various stream channel segments into types having similar hydrologic and geomorphic characteristics. These individual Channel Types (Table 1) in conjunction with soils and vegetation identify and describe a distinct RAZ. For incised or contained stream channels, the RAZ is defined and delineated by channel sideslope length and sideslope angle and encompasses adjacent soils with extreme mass wasting hazards.

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[1]Forest Service, Alaska Region Handbook on Land System Inventory. USDA Forest Service. 1982. FSH 2509.
[2]Integrated Resource Inventory Mapping Unit Descriptions, Chatham Area. Alaska Region Administrative Document Number 161 A. USDA Forest Service. 1986.

Channel Types[3] are used as the basis for grouping all the streams within a watershed into two broad groups: *Incised Stream Channels* and *Alluvial Stream Channels*. These two groups of Channel Types are listed in Table 1. Distinctly different geomorphic and hydrologic processes occur within these two groups of Channel Types. Incised stream channels are contained by the adjacent landform and on a RAZ map they appear as line segments of the RAZ (Fig. 1). Bank overflow is the distinguishing trait for uncontained alluvial stream channels. On a RAZ map they appear as the elongate polygon of the RAZ.

Bank overflow does not occur in the incised stream channels. Incised streams occur predominately in the upper valley and mountain slope erosional landscape positions where stream flows are well contained within steep v-notch channels (Fig. 1). Channel banks are steep and generally composed of large material, either consolidated bedrock or well packed boulders, rubble, and cobbles. The surrounding landscape have soil and vegetative characteristics indicative of riparian ecosystems. What riparian vegetation there is along these streams is often a thin band of hydrophyllic herbaceous plants, although narrow strips of alder, salmonberry, devil's club or currant sometimes form what could technically be defined as a riparian plant community.

Typically, landscapes adjacent to these well contained stream systems are composed of predominately terrestrial ecosystems. Mass transfer occurs in only one direction from the terrestrial landform to the channel (Fig. 1). Soils in the terrestrial areas are often shallow, colluvial in origin, coarse textured and subject to downslope movement. Leaves, forest litter and trees often move downslope to the incised stream. As the result of mass movement, this terrestrial influence zone often extends to the slope break above the sideslope. The width of the RAZ along these channels is determined by the degree of influence the adjacent terrestrial soils and vegetation have on the stream channels; these include V-notch sideslope length, height of the tallest tree that could fall into the channel and the occurrence of unstable soils on the site.

Incised channels are important nutrient source zones, but only limited nutrient processing occurs here. Large woody debris (LWD) and soil material are readily moved into the stream channel by mass wasting processes. LWD additions also occur through treefall resulting from windthrow or tree senescence. Recognition of this terrestrial influence zone is very important in riparian ecosystem management to assure protection of riparian dependent resources.

Alluvial (uncontained) channels have two-way interactions occurring between the adjacent landform and the channel (Fig. 4). These stream segments occur on floodplain, alluvial fan and dissected foot slope landforms. These are depositional landforms that occur mostly along lower valley or foot slope landscape positions, and are strongly influenced by moving water. Flooding is a fundamental geomorphic process in alluvial stream channels. These systems can be thought of as two way systems in which erosional inputs to the stream from the landscape are equivalent to depositional outputs from the stream to the landscape. Channel banks are shallow and streams commonly overflow onto the adjacent landscape depositing sediment and nutrients, supplying water to the ground surface and shallow

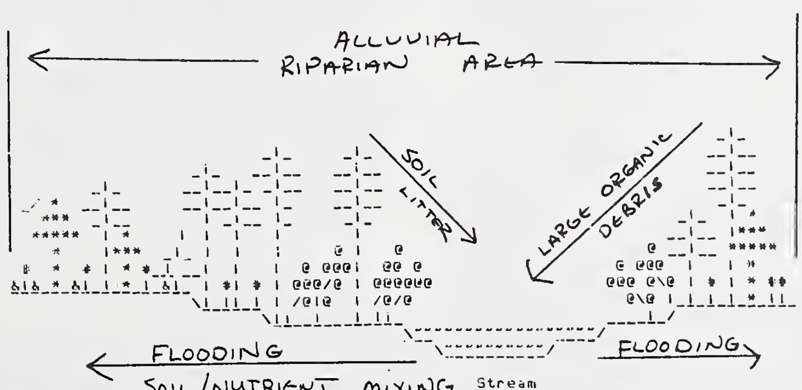


**Figure 4. An alluvial Riparian Area cross-section, two-way system.**

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[3]Channel Type Taxonomic Legend, USDA Forest Service Region 10. FSH 2609.24-22. Aquatic Habitat Management Handbook, March 1988 Draft.

alluvial aquifers. Lateral channel migration and floodplain erosion carry sediment back into the stream channel. These processes are reflected in the soils and plant communities which persist over time in the streamside zone. The Riparian Landforms are thus shaped over time by stream processes including: flooding, erosion, sediment transport, and sediment deposition. Many Riparian Landforms are also influenced by the presence of the low gradient, large, third or fourth order stream systems that maintain high water table and provide subirrigation of floodplain soils. The riparian ecosystem in turn provide the stream ecosystem organic and soil materials in the form of sediments and allocthonous food material and large woody debris. Vegetation on the riparian landscape slows overbank flow thereby dissipating flood energy. Mass transfer occurs through bank erosion, channel migration and overflow, leaf fall, and blowdown/tree fall. Alluvial channels are important nutrient source and processing zones, and they generally contain a richer diversity of aquatic organisms than the incised channels. On alluvial stream channels, the Riparian Area may be very broad and the adjacent terrestrial ecosystem may not directly influence the Riparian Area.

Alluvial (uncontained) Channel Types (Table 1.) have a maximum RAZ width delineated by the adjacent Riparian Landform. In cases where a Riparian Landform has not been mapped adjacent to the uncontained Channel Types NFMA dictates a minimum riparian strip of 100 feet adjacent to perennial streams. For some of the larger Channel Types a minimum 150 ft. wide band on either stream bank has been defined as the RAZ. These contained Channel Types, having no associated riparian landform due to their upland position, appear as linear features on the RAZ map.

*Level III - Riparian Area*

As previously defined the Riparian Area is a map delineation comprised of the aquatic and riparian ecosystems. The Riparian Area is mapped on GIS by combining the channel type data layer with the Soil/Plant Association map data layer (referred to all the CLU - common land unit in Alaska Region database) and adding these to the existing RAZ map (Fig. 3). The Riparian Area is mapped on the basis of similarity of soils and Plant Associations. Along a flood disturbance continuum, youthful soils on active floodplains support plant communities resistant to the impacts of flooding. These Riparian Areas are mapped separately from soils and Plant Associations of the more stable fluvial surfaces within the RAZ. Commonly 5 to 12 different Riparian Areas collectively make up the RAZ (Fig. 5). Adjacent non-Riparian Areas are covered by the RAZ. In cases where riparian soils and Plant Associations are not mapped along a stream segment then a 100' to 150' wide Riparian Area is designated on both sides of the channel.

At the Riparian Area level Channel Type mapping units provide data about fisheries habitat, water quality, channel stability, water volume, stream power and flooding characteristics. The Soil/Plant Association data provides interpretations for soil mass movement potential, erosion and transport of sediment, soil fertility, wildlife habitat, timber regeneration and old growth forest character. These basic interpretations are aggregated up through levels of the hierarchy. Combined with Channel Type mapping, the Soil/Plant Association map can more accurately determine flooding frequency, flood magnitude and intensity, erosion potential, sediment transport potential, habitat relationships for fish and wildlife, timber productivity and timber regeneration potential.

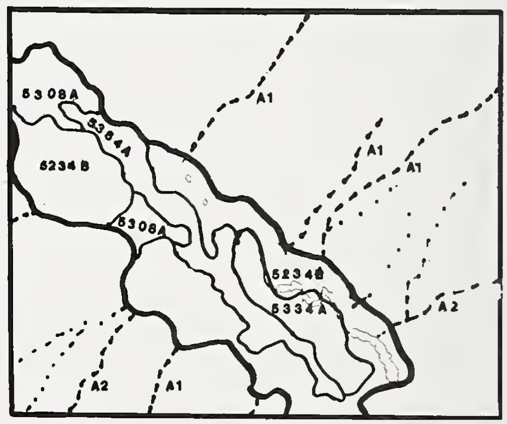


**Figure 5. A typical distribution of Riparian Area polygons within a Riparian- Aquatic Zone for a forested, floodplain landform in Southeast Alaska.**

A typical Riparian Area occupying a floodplain zone in the Chatham Area of the Tongass National Forest is C3-5364A (Fig. 6). Fluvial processes tend to be intense, frequent and generally override all other geomorphic processes. Flooding events typically occur on a one to five year cycle. The C3 Channel Types are characterized by high flow volume and poor flood flow containment. Lateral channel migration processes result in complex floodplain features including side-channels, sloughs, meander cutoffs, and multiple tier logjams[1]. Soils and Plant Associations on this site undergo yearly flooding with concurrent channel switching and channel migration. The Tonowek soil occupies 45% or more of the Riparian Area. Soil development is curtailed by continual yearly additions or losses of surface soil material slowing weathering processes which are otherwise dominant in soils not disturbed by flooding. It is composed of stratified sands, silts, and gravels located adjacent to the channel on an unstable floodplain, where frequent surface disturbance results from flooding. Dense thickets of pioneer shrub species such as alder, salmonberry, currant, elderberry and devil's club, resistant to and propagated by flooding, dominate understory vegetation types. Tree cover is less than 50%. Those which find a niche are red alder and Sitka spruce, both riparian dependent species.

In contrast to the above floodplain Riparian Area is Riparian Area B5-5234B occupying an alluvial fan (Fig. 7). Overland fluvial processes are infrequent and generally of low intensity. Sub-surface stream flow and sub-irrigated waterflow are overriding fluvial process. The B5 Channel Type is a network of moderately contained, perennial and 2nd order tributary streams. Soils and Plant Associations are much less influenced by disclimax events than in the C3-5364A map unit. The Tuxekan silt occupies 85% of the Riparian Area. It is a strongly developed soil (having time in place to weather), displaying several spodic soil horizons (Soil Survey Staff, 1975). It is also composed of stratified sands, silts, and gravels originating from flood deposition. Although soil parent materials have been transported and deposited by fluvial processes the frequency and magnitude of flood events are greatly reduced from that of

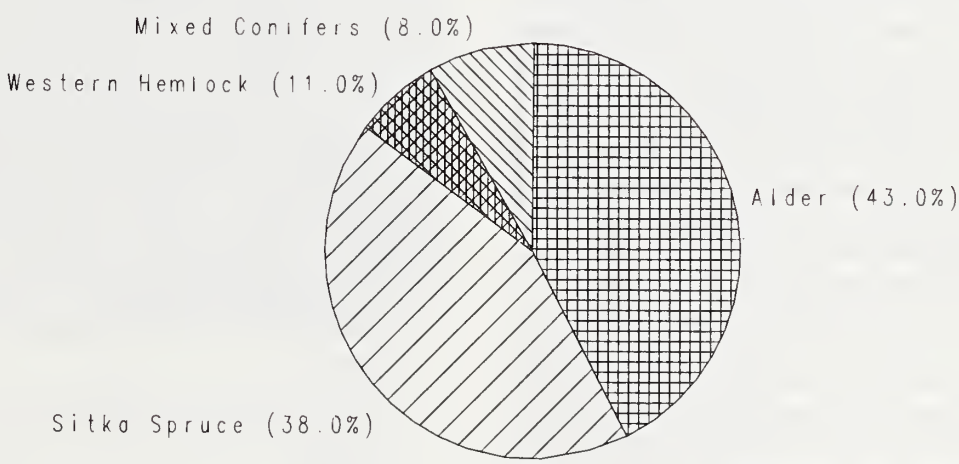


**Figure 6. Plant communities in a floodplain Riparian Area polygon (C3-5364A) mapped on the Chatham Area, Tongass National Forest.**

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[1]Integrated Resource Inventory Mapping Unit Descriptions, Chatham Area. Alaska Region Administrative Document Number 161 a. USDA-Forest Service. 1986.

C3-5364A map unit. It is located on stable alluvial fans dissected by aggrading B5 channels having a distributary drainage patterns. Riparian dependent Plant Associations requiring stability favor this area due to continual subsurface water flow and periodic surface disturbance from overland flow. Climax spruce forests dominate the area and tree canopy cover is greater than 70%. Dominant Plant Associations are the Sitka Spruce/blueberry-devil's club and Sitka spruce/blueberry.

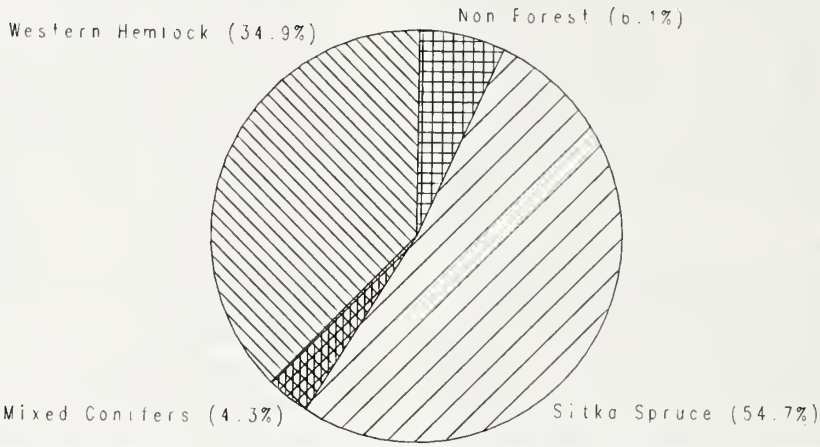


**Figure 7. Plant community distribution on an alluvial fan Riparian Area polygon (B5-5234B) mapped on the Chatham Area, Tongass National Forest.**

*Level IV - Riparian Site*

The Riparian Site is the lowest level of the hierarchy. It's initial utility has been as the data collection sites within the Riparian Area. The Riparian Site may range from as little as 1/10 acre to 20 acres in size. The Riparian Site is defined by a particular Plant Association growing on a specific soil next to a specific Channel Type. These components are the sum of physical and biological factors that describe the Riparian Site. Although it is not being mapped, the Riparian Site constitutes the basic data element for description and interpretation of the Riparian Area.

The importance of the Riparian Site is in the specificity by which each resource discipline can attribute information to it, thereby developing a unique multiresource perspective of what ecological processes interact on a particular site. By integrating information from the various resource inventories, the Riparian Site provides a better understanding of riparian processes and conditions than viewing it from a single resource perspective.

An example of two Riparian Sites occurring in one Riparian Area are Riparian Site C1 - Tuxekan-Sitka spruce/blueberry-devil's club close to the stream channel in Riparian Area 5364A and Riparian Site C1-Tonowek-Alder/Salmonberry for a site away from the stream but still within Riparian Area 5364A. These two Riparian Sites are interrelated in a typical floodplain soils/vegetation mosaic in the Chatham Area of the Tongass National Forest. The C1 - Tuxekan-Sitka spruce/blueberry-devil's club Riparian Site is characterized by the vegetation species that make up its name growing on a well developed, stable soil. The C1 - Tonowek-alder/salmonberry Riparian Site is comprised principally of weakly developed soils which experience frequent flooding. Alder and salmonberry persist in this relatively hostile habitat. The combined information derived from Channel Type, soil, landform and Plant Association inventories tells us the C1 - Tuxekan-Sitka spruce/blueberry-devil's club Riparian Site:

- is infrequently flooded,
- soils are eroded and transported with moderate ease,
- soils are highly productive,
- Plant Associations support high volume spruce forests,
- LWD recruitment to the stream, generally occurs at a rate and in a form consistent with fisheries habitat requirements,
- Plant Associations have moderate to high associated risk for brush competition to timber regeneration in part because of risk of soil disturbance during logging but mostly because of the flooding disturbance and consequent recruitment of competitive shrub species (Alder, salmonberry) to the site from the stream,
- fisheries habitat is good.

In contrast C1 - Tonowek-Alder/Salmonberry Riparian Site interpretations are:

- frequent season flooding,
- channel migration and abandonment is common,
- soils are eroded and transported easily,
- soils remain in a non-forest dis-climax,
- plant communities are riparian disturbance shrub species,
- LWD is less available for recruitment to the stream,
- the plant community if adjacent to a harvest unit may provide seed source of competitive shrub species resulting in brush competition,
- fisheries habitat is fair to good.

The Riparian Site has not been mapped and little work has been accomplished in the non-forest Riparian Areas. Doing so will strengthen interpretations at all levels of the hierarchy.

## Summary and Conclusions

Mapping riparian ecosystems involves combining Channel Type, Landform, Watershed, Soil and Plant Association inventories. Through the process of developing a riparian mapping hierarchy - Watershed, Riparian-Aquatic Zone, Riparian Area, Riparian Site - the Tongass National Forest Riparian Mapping System provides insights of interactions within the riparian ecosystem. This conceptual framework will enable Forest managers to interpret the landscape with better accuracy and more insight than separate inventories can provide.

Future field work will be needed to classify the nonforest riparian plant communities along streams and other water bodies. Additional work may be required to clarify some of the existing definitions and concepts. The most detailed levels of the hierarchy (Riparian Area and Riparian Site) will require field verification and further data collection to refine interpretations throughout the hierarchy.

The riparian ecosystem is a recipient of most cumulative natural and management induced impacts that occur in a watershed. Through research, monitoring, and land management planning at all levels of the riparian hierarchy, user groups can learn how best to cooperate to receive benefits from, while maintaining viability of the riparian ecosystem. Tis in turn will provide protection for several important riparian dependent resources including fish and wildlife habitat, and water quality.

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# Forest Planning Management Prescriptions and the Riparian Management Requirement

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National Forest Land and Resource Management Plans incorporate a ten step planning process. These include: 1) identification of issues, concerns, and opportunities, 2) development of planning criteria, 3) inventory collection, 4) analysis of the management situation, 5) formulation of alternatives, 6) estimated effects of alternatives, 7) evaluation of alternatives, 8) selection of an alternative, 9) approval and implementation, and 10) monitoring and evaluation. Resource management prescriptions are part of the development of planning criteria. Two riparian management prescriptions have been drafted for the Tongass Land and Resource Management Plan Revision. One prescription (13F) meets the National Forest Management Act's requirement for insuring that management practices have no serious and adverse affect on water conditions and fish habitat. The other prescription (14F) has a primary purpose of maintaining or enhancing riparian habitat for fish and other riparian dependent resources. Specific standards and guidelines for timber management activities have been formulated for each prescription.

# A Coordinated Approach to Identifying, Assessing, and Funding Watershed Improvements

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A 10 year (1979-1988) economic analysis of the Pacific Southwest Region's Soil and Water budget was developed to determine funding trends in the watershed improvement program. This analysis revealed that there is no consistent pattern in watershed improvement funding. However, over the ten year period studied, watershed improvement funding averaged about 13 % of total Soil and Water program funds. The analysis also revealed that there was no consistent correlation between increased funding and area (acres) of land actually improved. The study also revealed that the watershed improvement budget would need to be increased 100 % to meet the predicted funding needs for implementing watershed improvement goals outlined in Forest Land Management Plans. The study also revealed that opportunities to increase watershed funding could best be realized by coordinating improvement efforts using internal and external funding sources.

# Current Research Investigating Channel Unit Distribution in Streams of Southeast Alaska

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Current studies of the distribution of stream channel units are being conducted by the Watershed Management Research Group, Pacific Northwest Research Station, Juneau, Alaska. Channel units are spatial divisions of a stream channel distinguished by local hydraulics and channel morphology. They are characterized by geometric form, water depth, velocity, and surface slope, all highly variable with stream discharge. A simple division of alluvial streams into units of pools and riffles, based on depth and velocity, has been widely used in the past. Recently, however, researchers have found it useful to subdivide and expand this classification system by following schemes developed by Peter Bisson and Kathleen Sullivan, Weyerhauser Co. research group, to more completely describe channel units observed in steep, forested landscapes. Some of the more common channel units include riffles, cascades, plunge pools, lateral scour pools, eddy pools, glides, and others. Most channel units are commonly found in a wide range of stream sizes from larger rivers to small creeks. Work by Tom Lisle, USDA Forest Service, Pacific Southwest Research Station, has shown that in forested environments most pools are closely associated with large in-channel obstructions. These obstructions are commonly large woody debris, boulders, or resistant bank projections.

Quantification of channel unit distribution is of interest to hydrologists and geomorphologists concerned with high variability in the characteristics of flow, with the routing of sediment, and with resulting impacts on fish habitat. Several studies suggest, for example, that streambed scour and fill at riffles occur at different discharges than at pools. Likewise, timing and rate of bedload sediment transport vary between channel units in forested environments, which has important implications for the quality and stability of fish spawning habitat. Channel unit distribution is also of interest to fisheries biologists concerned with preferential use of these habitat elements. Different channel units provide distinct habitat conditions; their distribution therefore provides an index of habitat availability and characteristics. Recent work by Fred Everest and others at the USDA Forest Service, Pacific Northwest Research Station, has shown that fish production from a basin largely depends on the relative abundance of habitat types.

An improved understanding of the hydraulics and morphology of stream channels, resulting from the study of channel units, will aid land managers in dealing with several issues. Changes in debris loading resulting from timber harvesting and road construction may alter the distribution of channel units, thereby affecting fish habitat quantity and quality, erosion and sedimentation in the channel, and water quality. Land-use planners need models describing the routing of sediment through channel systems to predict potential downstream effects of altered sediment delivery from hillslopes. The potential for adverse cumulative watershed effects exists if, for example, increased sediment delivery to channels combines with altered sediment transport and storage downstream to cause stream bed aggradation, channel widening, and degradation of fish habitat. Although large woody debris is now commonly left in streams impacted by management, more information is needed to refine guidelines for management within riparian zones, which provide stream channels with the sustained supply of debris necessary for maintenance of channel units. The amounts, sizes, and types of debris required to provide adequate fish habitat are not well known. Systems of stream channel classification or typing have been developed to aid planners in predicting habitat distribution, and hydrologists and fisheries biologists with the USDA Forest Service, Alaska Region have classified most streams in southeast Alaska. Correlation of these channel types with salmonid production or with other systems of habitat classification has been low however. Information is also needed to improve guidelines for stream rehabilitation work by quantifying the detailed morphology of undisturbed streams.

Current research will contribute to these information needs of managers by (1) quantifying the abundance, form, and distribution of channel units in several southeast Alaska streams; (2) investigating the influence of independent physical variables on channel unit distribution; (3) investigating specific relations between channel units and in-channel obstructions such as large woody debris; and (4) investigating the effects of land management practices on channel unit distribution. Management practices of particular interest include timber harvesting within riparian zones, removal of large

woody debris from streams, and construction of fish-enhancement structures. At several study sites, fisheries biologists from the Pacific Northwest Research Station will sample fish populations to quantify relative abundance in various channel units and, by inference, the importance of these units as habitat.

# The U.S. Geological Survey Data Base: Streamflow and Water Quality in Southeast Alaska

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Stream gauges for determination of streamflow have been operated in Southeast Alaska -- Yakutat south to the Canadian border -- since 1909. Records range in length from 1 to 70 years at 132 gauging sites. The oldest operating stream gauge is Fish Creek near Ketchikan, beginning in 1915. The present gauging network consists of 22 gauge sites. Continuous stream temperature records, less than 5 years in length, have been collected at 43 sites. Chemical analysis of the waters of Southeast Alaska has been sparse and limited to determination of common ions. Streamflow sediment determinations have been limited in areal coverage and range of river stage. Sediment loads carried by streams at peak flows greater than mean annual peaks have not been determined.

# A New Look at Low Flows After Logging

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***Abstract.*** On the west side of Prince of Wales Island, a 51.6 square mile drainage basin was used to systematically evaluate low flow trends, before and after timber harvest. Both yearly flow duration curves and the 2 and 20 year recurrence low flow derived by Log Pearson Type III analysis, showed significantly greater low flows after timber harvesting 35 percent of the drainage area.

Evapotranspiration is one of the most important elements of the water balance in a watershed. The processes of water routing in a watershed are complex due to the many interactions and complex variables, such as climatic and vegetative characteristics and sub-surface conditions. In total, evapotranspiration plays a dramatic role in the baseflow characteristics before and after vegetative manipulation.

There has been, and still is, much concern regarding timber harvest and its effect on minimum flow, particularly to fish habitat and survival. The knowledge base regarding forest manipulation and its relationship to low flow in coastal, maritime Alaska is equivalent to alchemy and gold production. Let us investigate some of the mechanics of discharge in Southeast Alaska regarding low flows in particular. At present, the best data base available for a significant timber harvest area tied to adequate periods and quality of hydrologic records is for the Staney Creek watershed. The Staney Creek watershed is located on the west side of Prince of Wales Island, some 67 air miles north west of Ketchikan, Alaska.

The Staney Creek drainage basin is a relatively large watershed that has an area of 51.6 square miles, contains muskegs, and prior to harvesting, had a dense, high quality stand of large timber. The trees in this watershed are primarily Hemlock, Spruce and Cedar. The climatic influences on the area are dominated by the strong maritime weather cells that dominate precipitation and temperature in the area. The yearly mean precipitation for the drainage basin ranges from 100 inches in the lower elevations to 130 inches in the higher elevations.

In 1964-65, the U.S. Geological Survey (U.S.G.S.) installed a water level recorder (stream gage) near the mouth of Staney Creek, just prior to the commencement of logging in the drainage. Logging in the upper most reaches of the drainage began in 1967 with the harvesting of 2.3 percent of the watershed; by 1970, 10 percent of the basin had been harvested. Records of the harvested area are vague. Several records indicate released for harvesting rather than actual harvest and removal, therefore creating a built in lag error for recorded harvested area. Records are sufficient to develop a graph of the accumulated timber harvest over time in years (Fig. 3).

There has been much concern, accusation, approval and research (Chang et al., 1975; Harr et al., 1979; Harr, 1980; Harris, 1973; Meehan et al., 1969; Rice, 1981; Rothacher, 1973) regarding timber harvest and its effect on watershed hydrology, principally discharge peak, low flows and yield. Determining effects on watersheds such as Staney Creek, is difficult due to its large drainage area, and more so because of insufficient hydrologic data. Hydrologic data are usually lacking or too short in duration in the pre-harvest period, a period of calibration and assesing the watershed in its pristine hydrologic condition. In order to have an adequate number of years of pre-harvest data, hydrologic data for periods when harvested area was less than 10 percent of the total harvested area were considered pre-harvest conditions.

In the literature there are pros and cons regarding timber harvest and its effects on increasing or decreasing water yield. Water yield being the quantity of water expressed as a continous rate of surface flow, a volume per unit of time (acre-feet per year), passing a point in a watershed. The purpose of the study was to determine whether or not harvesting timber had changed the water yield of Staney Creek by a measurable amount.

In order to determine a change in water yield, the accumulated water yields of two stream gages are plotted against each other. This is known as a double mass analysis(Searcy and Hardison, 1960) or curve. In this case, one station is the stable control station. The nearest station with reliable discharge records for this investigation is Old Tom Creek some 32 air miles south east of Staney Creek, on the eastern side of Prince of Wales Island. If there is an increase or decrease in water yield at any time there will be a deviation from the plotted relationship as indicated in (Fig. 1). The deviation in this case indicates an increase in the water yield of Staney Creek. This pronounced increase occurred in the 1972 water year, increasing again the following year.

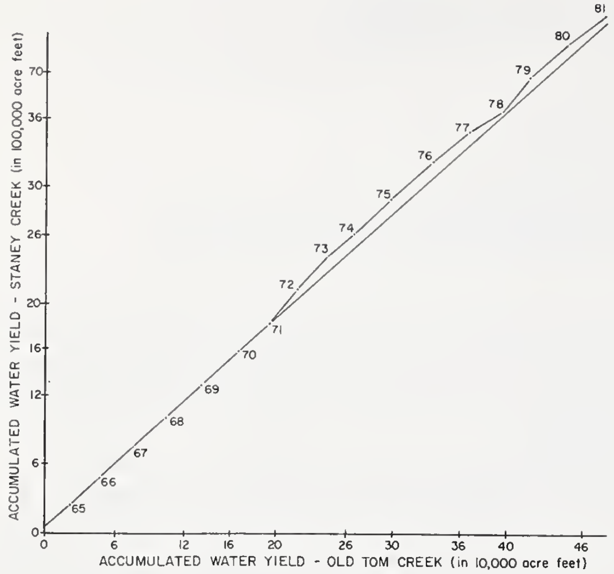


**Figure 1. Double-mass analysis comparing accumulative water yields in Staney Creek to Old Tom Creek. (USGS data, 1965-1981)**

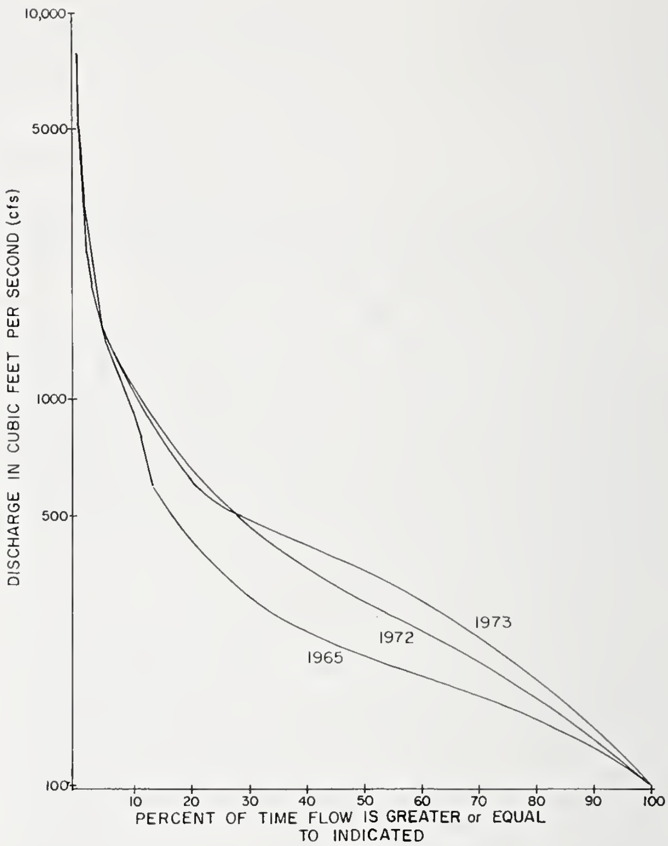


**Figure 2. Annual flow duration curves for Staney Creek, Prince of Wales Island.**

## Method

To ascertain the influence on flow regime of harvesting in Staney Creek watershed, a flow duration analysis was done using daily discharge for each year over the period of record. The flow duration curve is a cumulative frequency curve of a continuous time series, displaying the relative duration of various magnitudes (Fig. 2). The shape of the curve is influenced by topography, geology, vegetation cover, land use, and precipitation characteristics. The curve displays the percent of time flow magnitude is equal to or greater than the indicated flow (Fig. 2).

## Results and Discussion

When flow duration analysis was applied to the Staney Creek stream flow data it graphically demonstrated a noticable change, in the mean to low flows after timber harvest (Fig. 2). This change can be seen in (Fig. 2), comparing data of three years, one prior to logging (1965) and two during the peak of the timber harvest effort at this peak (1972-73) 21 and 22 percent of the area had already been harvested. The curve for the 1965 water year is very typical of most watersheds in southern southeast Alaska, a uniform decaying power curve. The years 1972 and 73 were periods of relatively intense timber harvest and in these progressive years there was an increase in the mean and low flow range. This increase is shown by the upward curving of the lower limb of the flow duration curve(Fig. 2).

The indication of increased low to mid range discharge is no doubt indicative of the loss of canopy interception and evapotranspiration. The increased volume of soil water stored and soil phreatic water would gravity feed to the tributaries and mainstream for a period much greater than occurs in an unlogged condition.

Though the overall average low to median flows have increased after timber harvest, has logging depressed the yearly average summer seven day low flows? The average seven day low flow is the average of the seven lowest summer low flows for the year. This was computed for each year of record, and plotted in (Fig. 3). This graph shows an increasing trend in discharge, even in an extreme dry year such as 1978. In order to determine any relationship between accumulated timber harvest and the seven day mean low flow, the accumulated percent of area logged was plotted in (Fig. 3) strongly suggesting an increase in low flow corresponding with the incremental increase in area harvested. An approach to analyzing low flows is best done by

separating pre-harvest and harvest discharges as discussed previously in this paper. To determine the recurrence intervals of the associated low flows, the Log Pearson Type III analysis was used. By this method recurrence flow ratios can be used to compare slope differences between the before and after logging low flow discharges.

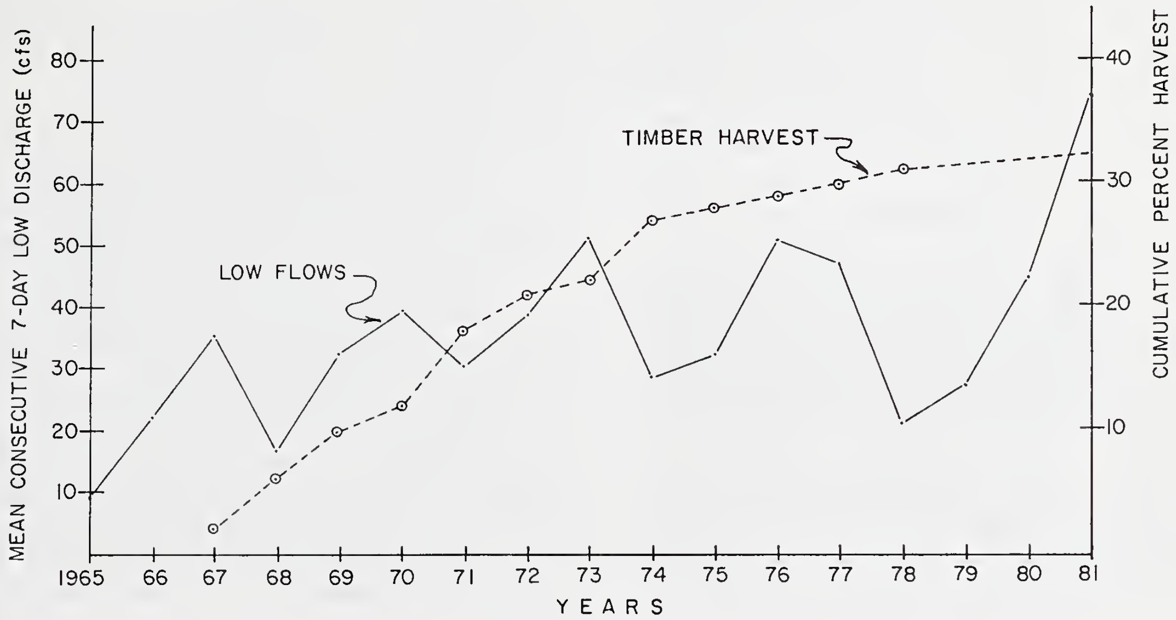


**Figure 3. Mean consecutive 7-day low discharge in Staney Creek in relation to cumulative timber harvest (percent of watershed) from 1965 through 1981.**

A comparison of the seven day low flow discharge recurrence interval for before and after logging for Staney Creek (Table 1 ) is an example.

**Table 1. 7-day low flow recurrence discharges**

| | Before Logging | After Logging |
|---|---|---|
| 2 year low flow | 22 cfs | 37 cfs |
| 20 year low flow | 8 cfs | 20 cfs |

The ratios of the 2 and 20 year low flow recurrences for before and after logging, using the data in Table 1:

Before logging, 22/8 = 2.75
After logging, 37/20 = 1.85

The principle of this analysis is that the lesser the quotient, or slope, of the ratio of 2 and 20 year 7-day low flows, the more base flow available in the basin. The sub-surface water can be from natural storage as alluvial aquafers, glacial systems or as in this case induced stored water from the process of timber harvest, thus the lack of evapotranspiration. In very porus drainage systems with poor natural storage, the ratio slope would be quite large. In the Staney Creek basin, the percent difference in the low flow ratio slopes is 33 percent less after timber harvest. The percent increase in the 2-year and 20-year low flow after timber harvest was 168 and 250 percent respectively.

## Conclusion

From the step wise methodologies used it is apparent that from the available USGS surface water records of the Staney Creek gage there was an apparent increase in low flows after logging. Due to the lack of sufficient long term-surface water and precipitation data, a more comprehensive analysis could not be made.

The increase in water yield that began in the 1972 water year stablized in 1975-76, then begins to return to

some state of quasi-equilibrium, however the existing seven day low flow data is inadequate to substantiate this. The re-activation of stream gaging in Staney Creek is proposed for the spring of 1989, with the addition of another stream gage in the upper reaches of the watershed. There may be an adequate and sufficient data base after several years of stream gaging that further trends could be evaluated and a model could possibly be developed for the Staney Creek watershed.

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# Input and Depletion of Woody Debris in Alaska Streams and Implications for Streamside Management

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Natural rates of input and depletion of large woody debris (LWD; fragments >l0 cm diameter and >3 m long) in Southeast Alaska streams were studied to provide a basis for managing streamside zones to maintain LWD for fish habitat after timber harvest. Large woody debris was inventoried by size and decay classes in 32 reaches of a variety of channel types in undisturbed old-growth forest, and more than 250 pieces were dated from the age of trees growing on them. Longevity of LWD in the streams was directly related to bole diameter. Small pieces (<30 cm diameter) were all less than l00 yr old, whereas large pieces (>90 cm diameter) were up to 226 yr old. Assuming steady-state conditions in old-growth forest, LWD depletion rate was assumed to equal input rate which was calculated from the percentage abundance and average age of LWD in the decay classes. Annual depletion ranged from l.2% of large pieces in all channel types to 3.0% of small pieces in C2 channels (fourth-order, bedrock-controlled streams). A model of LWD changes after logging, which accounted for LWD depletion, LWD input from second-growth trees, and distance from the stream to LWD sources, indicated that clearcutting without buffer strips along streams reduces LWD >60 cm diameter by 75%, and the minimum level of LWD is reached 90-l00 years after logging. Because almost all LWD in streams comes from within 30 m of the stream bank, a 30-m buffer on both sides of the stream should maintain LWD levels in the stream after logging.

# Modeling Fish Habitat and Stream Class Using Channel Classifications

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Channel type inventories of Tongass National Forest streams are used in number of ways in the Revision of the Tongass Land Management Plan and other planning and implementation activities across the Forest. For the fish resource, three major uses of the channel type inventories are employed in conjunction with the ARC/INFO Geographical Information system (GIS). These uses are: 1) to model the quantity of timber available from riparian areas as a result of application of different land management prescriptions, 2) to model the fish habitat capability of Forest streams, and to predict effects on the fish resource resulting from different land management allocations, and 3) to predict stream class, or display the extent of anadromous and resident fish habitat. We presented detailed information for the second two uses, while Wilson and Kessler addressed the quantity of timber available in riparian areas in their presentation.

# Hydrology of the Russell Lake-Old Situk River Watershed

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***Abstract.*** The advance of the Hubbard Glacier in 1986 created the worlds largest present-day glacial dam lake in Russell Fiord. Had the ice dam held and Russell Lake continued to fill, runoff thru its historic outlet into Old Situk Creek would have resulted in significant changes to watersheds on the Yakutat Forelands near the village of Yakutat, Alaska. This paper summarizes the results of hydrologic analyses conducted to predict the magnitude of potential future overflow events should the Hubbard Glacier ice dam re-form at the mouth of Russell Fiord. During the summer of 1986, runoff for Russell Lake was calculated by measuring lake rise between 20,000 and 30,000 cubic feet per second (cfs). This runoff is roughly equivalent to 20 times the combined summer flow in Situk River and Lost River the two principal streams that currently drain the Old Situk River watershed. Precipitation and watershed data were analyzed using two flood runoff models. A flood storage and routing analysis was also performed. Results indicate that extreme flood runoff events could result in lake overflows of 50,000 cfs. The impact of Russell Lake flooding on the Situk and Lost Rivers will include significant changes to channel morphology, water quality, fisheries habitat, and stream flow regimens. These changes will likely result in adverse effects to existing sports and commercial fisheries uses, at least in the short term.

*Historic Russell Lake*

Historically the Russell Lake watershed and Yakutat Forelands have been dominated by snow and ice cover and shaped by glacial runoff processes. The entire Yakutat Bay and Russell Fiord region was covered by glaciers within the last 6000 years.

Due to the region's relatively easy access numerous glaciology studies have been conducted. As early as 1823 maps showing the extent of glacial advance and retreat were made by explorers of the region. In 1892, I. C. Russell with the Geological Survey studied the area. Between 1905 and 1913 Tarr and Martin published works on Alaska glacier studies which included the Yakutat Bay region (Tarr, 1909; Tarr and Martin, 1914).

Tarr and Martin (1914) found evidence that an 1800's advance of the Nunatak glacier pushed southeastward into Russell Fiord to within 7 miles of the head of the bay. The extent of this advancement is evidenced by a subaqueous terminal moraine in Russell Fiord. The snout of this Russell Fiord glacier formed the northern edge of the historic Russell Lake (Figure 1).

Oral histories collected by deLaguna (1964) indicate that until the 1800's, Russell Fiord was blocked to the north by glacial advancement. The northern edge of the freshwater lake draining to the south via Old Situk Creek extends between Beasley Creek and Cape Stoss. This is four miles south of the southern extent of glacial advancement located by Tarr and Martin. According to de Laguna, between 1850 and 1875 the glacial dam in Russell Fiord broke, draining the fresh water lake into Disenchantment Bay and cutting off the flow from Russell Lake into Old Situk Creek. The evidence presented by these observers suggest that Russell Lake overflow into Old Situk Creek stopped between 110 and 165 years ago.

Age estimates of vegetation growing within the historically active channel of Old Situk Creek were made in September of 1987. Dominant trees were sampled along stream levees and bars that were deposited during the last Russell lake flood event. Sitka spruce tree cores indicated maximum ages of 90-100 years old. Assuming that establishment of the spruce takes 10 to 20 years after the channels dryed up, the tree core data indicate that Russell Lake overflow ended between 100 and 120 years ago corroborating the oral history accounts of Russell Lake draining.

*Future Watershed Condition*

More recent glacial events have again had dramatic influences on the hydrology of the Russell Fiord area. During May of 1986, the Hubbard Glacier advanced past Osier Island to block off the mouth of Russell Fiord at Disenchantment Bay. Russell Lake once again began to fill. Daily increases in lake level were as high as one foot, until October 8, 1986 when the glacial dam broke draining the lake.

The Hubbard Glacier is likely to continue to advance and again block Russell Fiord in the near future (Mayo, 1987). If the Hubbard Glacier dams Russell Fiord for an extended period, several dramatic changes will occur within the Russell-Situk River watershed. The water level in Russell Lake will inundate 14 square miles of mostly vegetated shoreline. The water surface area will increase from 76 square miles to 90 square miles. When the lake reaches a level of 128 feet above sea level, it will overflow into Old Situk Creek.


**Figure 1. Situk River-Russell Lake Watershed located in southeast Alaska.**

Under this scenario the size of the Old Situk Creek and Situk River watershed will increase by almost ten times from 83 square miles to 806 square miles. This will cause dramatic changes in the flow regimen, stream channel and floodplain characteristics of the river system. Sediment loads will increase greatly as a new channel network is formed. Groundwater levels and flows in groundwater fed streams in the vicinity of the Russell Lake will also likely be effected by the lake rise.

The general area effected by these changes is best indicated by the historic floodplain surfaces and relic channels from previous Russell Lake outflow events. These floodplain and channel features can be easily identified on maps and air photos of the Situk River area. However, the need for hydrologic information was identified to more accurately predict the effects of future Russell Lake outflow events (USDA, 1988).

**Table 1. Present Russell Fiord Watershed Condition.**

| Cover Type | Area Total | Area Portion |
|---|---|---|
| | mi² | % |
| Trees and Shrubs | 82 | 11 |
| Water Surface | 76 | 11 |
| Rock and Barren | 215 | 30 |
| Snow and Ice | 350 | 48 |
| Total Area | 723 | 100 |

*Russell Fiord Watershed Characteristics*

The sparsely vegetated watershed contributing runoff to Russell Fiord is 723 square miles in area. Predominant cover types are: snow, ice, rock, and alpine tundra (Table 1).

Precipitation estimates for the watershed ranges from 150 inches per year at sea level to 200 inches per year at higher elevations (Ott, 1979). Precipitation distribution throughout the year consists of mostly rain at the lower elevations and snow above 2000 feet. June is typically the driest month, with October being the wettest. During the summer of 1986 when Russell Lake was filling; June and July precipitation was near normal while August 1986 was a near record wet month with 24.54 inches of rainfall at sea level. An extreme high rainfall of 48.34 inches was measured during September 1987 (27.10 inches was the previous record high rainfall). Rainfall data is based on a 30 year record from the Yakutat Airport, National Weather Service Station.

Temperatures are mild in the region, with mean daily summer maximums of 60 degrees Fahrenheit. Winters are cold, with highs below 32 degrees Fahrenheit in January and lows sometimes dropping below 0 degrees Fahrenheit.

Elevations within the Russell Fiord watershed range from sea level in Russell Fiord to over 9,000 feet in the St. Elias Mountains. The accumulation zones of mountain glaciers start between 1500 and 2000 feet. Snow and ice fields are found mainly at higher elevations, except for the Hubbard and other large valley glaciers that extend near or to tidewater. Because of recent deglaciation, vegetation occupies only 11% of the watershed area. Cottonwood, Sitka spruce, alder, willow, and devils club extend from sea level to 1000 feet.

## Results and Discussion

*Lake Inflow/Precipitation Model*

Between June and October of 1986, levels of Russell lake were recorded by the U.S. Forest Service and the U.S. Geological Survey during the blockage by the Hubbard Glacier (Seitz et al, 1986).

An area-capacity curve for Russell Lake was developed using 1:63000 scale topographic maps. Utilizing the lake level data and the area-capacity relationship, an inflow hydrograph for the lake was generated (Figure 2). Lake level data between June 2 and August 11, 1986, were collected intermittently (shown as a dashed line). Between August 11 and October 7, 1986, lake stage was recorded continuously (shown as a solid line). The highest mean monthly inflows were 20,000 cubic feet per second (cfs) measured during July and August. Russell Lake inflow averaged 33,000 cfs during the maximum summer runoff period during the first two weeks in August. The maximum one day flow was 44,000 cfs.

Daily rainfall at the Yakutat Airport was compared with the Russell Lake inflow hydrograph. Rainfall during the periods August 8-13 and August 24-27 resulted in major runoff peaks. Daily rainfall and inflow to Russell Lake were significantly correlated ($R^2=0.93$) (Figure 3).

Using the regression equation in Figure 3, peak inflow values can be estimated for different size rainfall events in the Yakutat area. Assuming glacier snowmelt runoff is comparable to that which occurred in August of 1986, and using the regression equation to compute runoff for a 5.6 inch rainfall (the highest 24 hour rainfall on record for August), a peak daily inflow rate of 55,000 cfs is predicted. This flow is comparable to five times the June 1987 flow in the Dangerous River at Harlequin Lake and about 10 times annual peak flows in the Situk River. Using the highest potential rainfall rate ("probable maximum rainfall"(Miller, 1963)) 24 inches in a 24 hour

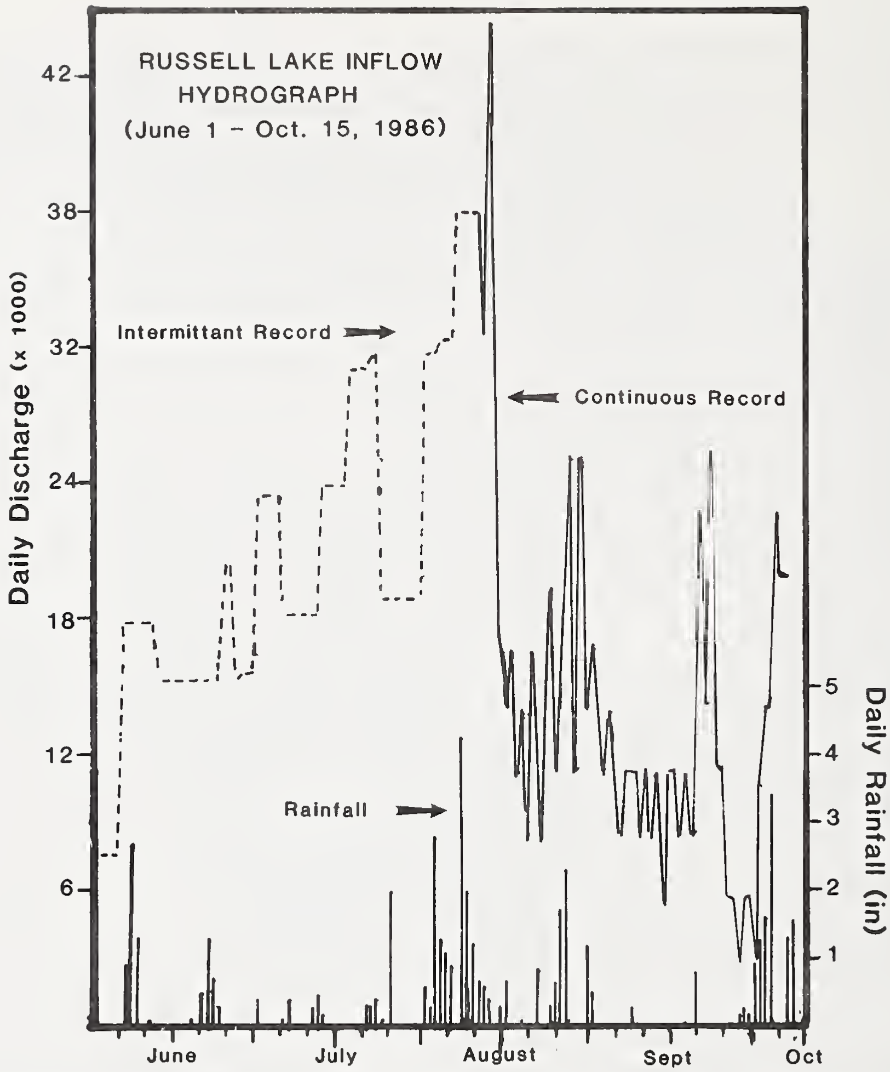


**Figure 2. Daily inflow to Russell Lake and daily rainfall at Yakutat Airport, June-October 1986.**

period, a 220,000 cfs lake inflow is generated by the rainfall regression model.

It is important to note that these inflow rates into Russell Lake will not be equivalent to the outflow to Old Situk Creek. A lake storage and routing analysis by Paul (1988) shows that a daily peak inflow of 220,000 cfs would be significantly attenuated by Russell Lake, resulting in a peak outflow discharge of 52,000 cfs into Old Situk Creek. An inflow discharge must be sustained for a minimum of 3 days to be roughly equivalent to outflow discharge.

A major limitation of this rainfall-lake inflow model for Russell Lake is that the model assumes no change in the glacier snowmelt runoff relationship observed in the summer of 1986. This snowmelt is likely the principal runoff component for the watershed which has a 50% permanent ice and snow cover. Rainfall runoff only effects peak runoff during *sustained* periods of rainfall that occur in conjunction with periods of peak snowmelt, as observed during the first two weeks of August 1986. The confidence limits for runoff predictions made from rainfall rates that are beyond the limits of observed data (4.4 inches in 24 hours) can not be estimated.

*Regional Runoff Model Predictions for the Russell Lake Watershed*

A regional runoff model was also used to determine maximum expected runoff from the Russell Lake watershed. The model, developed by the U.S. Geological Survey (Parks, 1985), was used to estimate potential peak runoff. A stepwise multiple regression approach was used to develop equations to determine: mean annual flow (Qm), 50 year return interval flood (Q50), and 100 year return interval flood (Q100) ( A 100 year return flood has a 1% chance of occurring in a given year). Watershed area and average annual precipitation

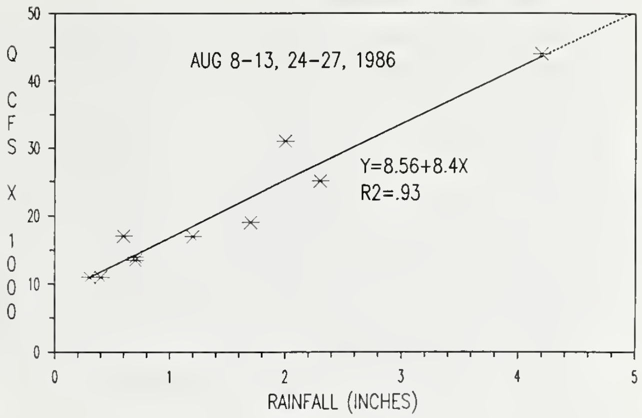


**Figure 3. Correlation between rainfall and Russell Lake inflow.**

are the independent variables used to predict runoff in this approach. When these regression equations were applied to the Russell Lake watershed, the values of Qm = 8,650 cfs; Q50 = 73,000 cfs; and Q100 = 76,000 cfs were obtained. Standard error (SE) of the Q50 and Q100 runoff estimates are +69% and -41% (uneven SE are due to log transformation of the variables).

Validation of the USGS runoff model predictions is difficult because there are extremely limited stream flow data from large glacial streams in the Yakutat area. Two instantaneous discharge measurements of 10,800 cfs and 11,700 cfs were made in June and September of 1987 on the Dangerous River, which drains a 270 square mile glacial watershed adjacent to the Russell Fiord watershed.

Runoff values for this smaller watershed using the USGS model are 3,300 cfs for mean annual discharge and 35,500 cfs for a 50 year flood event. The Dangerous River discharge measurements (representing high summer flows) fit within the range of runoff predicted by the USGS model.

The USGS regional runoff model also has major limitations for use in predicting Russell Lake outflow. Large glacial watersheds were used to develop the regression equations. These gauging records in Southcentral Alaska are not necessarily representative of runoff patterns in the Yakutat region. The lack of precipitation data in the Yakutat area, particularly for interior high elevation zones of the Russell Lake watershed, is another major limitation that may reduce the accuracy of runoff predictions. Most importantly, the USGS model does not incorporate lake storage capacity which is a major factor influencing outflow from the Russell Lake watershed.

The lack of stream flow and precipitation information for the Yakutat area in general and for the Russell Lake watershed specifically, make any flood predictions tenuous. Sustained weekly runoff into Russell Lake measured at 20,000 to 30,000 cfs, during the summer of 1986, is the best indicator of likely peak outflow to Old Situk Creek. Information provided by the two runoff models discussed in this report and flood storage and routing analyses (Paul 1988) indicate that *extreme* runoff events could potentially result in outflows from Russell Lake with a magnitude of 50,000 cfs.

## Resource Management Consequences of Russell Lake Flooding

A future Russell Lake overflow event will have significant effects on facilities, cultural sites, and commercial, subsistence and sports fisheries in the Old Situk Creek and Situk River floodplains. Figure 4, is a map of the probable areas affected by flooding (flood limits). It shows the likely flow paths for 20,000 and 50,000 cfs magnitude floods. This map was developed using floodplain channel profiles and the U.S. Weather Bureau "DAMBRK" flood routing model (Paul 1988). Although additional field verification of floodplain cross section profiles in the lower Situk River may be needed to test these results, some tentative conclusions can be drawn from the available information.

Residences and facilities in the vicinity of the Yakutat Airport are not likely to be effected by Situk flood waters. The Forest Highway 10 bridge over the upper Situk River should also not be effected. The road near Old Situk Creek will be lost and the Lost River road between the Lost River bridge and Situk Landing will be inundated by flood waters. Dramatic changes to drainage channels in the Lost River and lower Situk River and Old Situk Creek can also be anticipated.

The severity of flood impacts will depend to large degree on the longevity of any future ice dams in Russell Fiord. Specific changes to stream channels cannot be described with certainty due to such factors as the timing of runoff events emanating from the lake; the redistribution of organic debris within the channel network; and the quantities of sediment entrained and re-deposited during the initial flood event. Differential uplifting and subsidence along the Forelands, resulting from isostatic rebound and seismic activity, are other factors that may cause changes in historic drainage patterns (Paul, 1986).

Assuming the ice dam lasts for a period of several years, a major new river system will evolve on the Yakutat Forelands (Figure 4). Floodplain investigations indicate that channels in the Lost River area will become the

primary drainage channel (Paul, 1988). The course of the present Situk River should remain about the same but significant channel widening will likely occur.

Fish habitat in Old Situk Creek and Situk River below the confluence with Old Situk Creek will be impacted to the greatest extent by Russell Lake flooding. A high percentage of main channel spawning habitat in these streams could be destroyed initially due to extensive streambed scour and sediment deposition. Excavation of relic channels in the Lost and Situk River floodplains is expected to occur largely within the first 3 to 5 years after the lake overflows.

Anadromous fish rearing potential could occur in substitute areas within secondary floodplain channels that have consistent water flow. Large woody debris and riparian vegetation along such secondary channel margins is important to provide cover and refuge from high flows. Potential impacts to rearing habitat may be partially offset by expanded seasonal rearing habitat along secondary floodplain channels and sloughs. The cooler glacial waters from Russell Lake may affect growth and distribution of salmon in the Situk River, but studies in the Taku River indicate that sockeye and Chinook salmon successfully rear in colder, turbid glacial waters (Murphy et al. 1988, Thedinga et al. 1988).

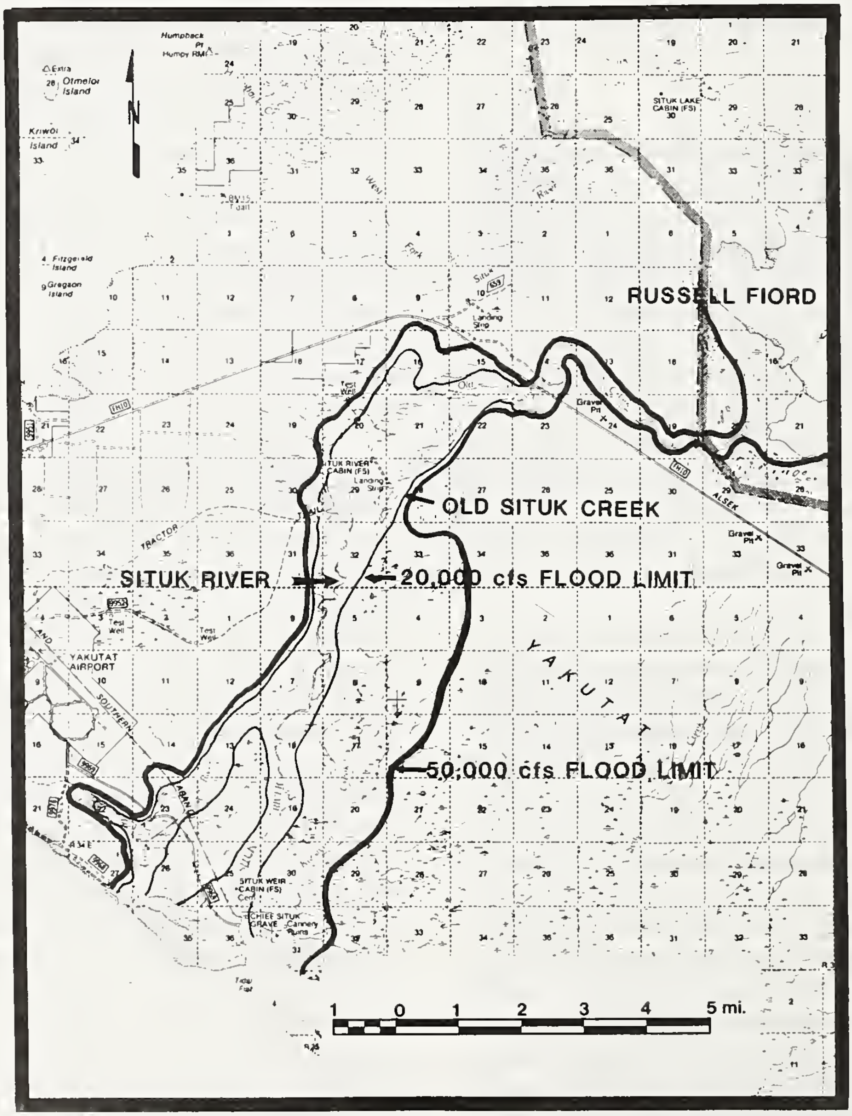


**Figure 4. Map of proposed projected Russell Lake flood limits (Paul, 1988.)**

Facilities, and cultural sites within the floodplain boundaries will also be significantly impacted by the predicted flood events associated with a Russell Lake overflow. Forest Highway 10 at the old Situk Creek crossing would be cut as would the Lost River road at the Lost River bridge. Several cultural sites adjacent to Tawah Creek, Lost River and Situk River (Davis 1987) may be destroyed by flood waters. The Forest Service cabins on the Situk River and the middle Situk landing strip may also be destroyed. Approximately 50 commercial fishing camps located along the Situk River will need to be re-located. However, it is unlikely that the Yakutat Airport would be effected by flood events.

Groundwater fed channels located on the Russell Lake moraine will likely be effected by higher water tables caused by the filling of Russell Lake. Groundwater runoff through permeable moraine deposits is currently the predominant source of Old Situk Creek flow as well as for many smaller ephemeral streams. Increased hydraulic gradients associated with the rise in Russell Lake should result in some increased base flow for these groundwater fed streams.

Increased groundwater interflow derived from Russell Lake runoff could improve fish habitat in some areas. The area between Old Situk Creek and Situk River above Forest Highway 10 represents the greatest potential for elevated water tables and the best opportunity for construction of rearing ponds and spawning channels to mitigate the effects of downstream habitat damage caused by Russell Lake flooding (Figure 5).

Other potential changes in surface water quality resulting from Russell Lake overflow events, which could impact aquatic productivity include changes in water temperature, dissolved solutes, and turbidity. Very limited water quality information is available for Russell Lake (in 1986), as well as for streams within the Old Situk Creek and Situk River watersheds. Additional work is planned to help characterize potential water quality impacts (USFS, 1988).

## Mitigation Measures

*Diversion Structures*

A diversion structure located in the head waters of Old Situk Creek has been proposed as a means of protecting the main Situk River from Russell flood waters. The engineering feasibility of such a structure is discussed by Paul (1988). The biggest drawbacks of a diversion structure are prohibitive costs and the lack of downstream topographic controls that will contain the large volume of water and sediment generated by an overflow event. In short it would be very difficult and expensive to divert Russell Lake overflow from the Situk channel network.

*Floodplain Clearing*

Removal of brush and trees within the Situk-Lost River floodplain prior to Russell Lake overflow, has been suggested to speed up the development of a stable drainage network that will handle increased runoff from Russell Lake (Paul, 1988). Extensive floodplain vegetation removal however, will be detrimental to the recovery of Situk River fishery resources. Fisheries habitat would be significantly effected in the short and long term with the loss of streamside vegetation and inchannel debris structures. Riparian vegetation and inchannel debris accumulations are two of the most important factors in determining fish habitat stability and productivity (Reiser and Bjornn, 1979). Extensive removal of riparian vegetation will reduce aquatic food sources, stream bank cover and pool development, thus compounding adverse fisheries impacts that will result from Russell Lake overflow.

*Fish Habitat Replacement*

Development of groundwater fed rearing ponds and spawning channels as a replacement for flood impacted Situk River fish habitat are promising mitigation options. The area above Forest Highway 10 between Situk River and Old Situk Creek above FH 10 has good potential for these kinds of habitat improvements (Figure 5). There are many factors that make this area suitable: shallow groundwater sources presently exist, road access is good for construction and maintenance of habitat structures, and site location will allow fish recruitment from and migration to both the Russell-Situk and the Situk Lake stream systems. Greens Pond, a successful fish rearing pond project, is located in this area. The main factor limiting potential for additional enhancement projects in this area is the quantity of groundwater that can be intercepted to provide year around flow to channel and pond networks.

*Other Measures*

Possible non-habitat related fisheries restoration or enhancement options include fish stocking, and construction of hatchery or egg incubation facilities. These options fall under the jurisdiction of the Alaska Department of Fish and Game and may be evaluated in the future. Fish stock enhancement projects on national forest land could potentially be planned and constructed thru cooperative efforts involving the Forest Service, ADF&G, Aquaculture Groups or Native Corporations.

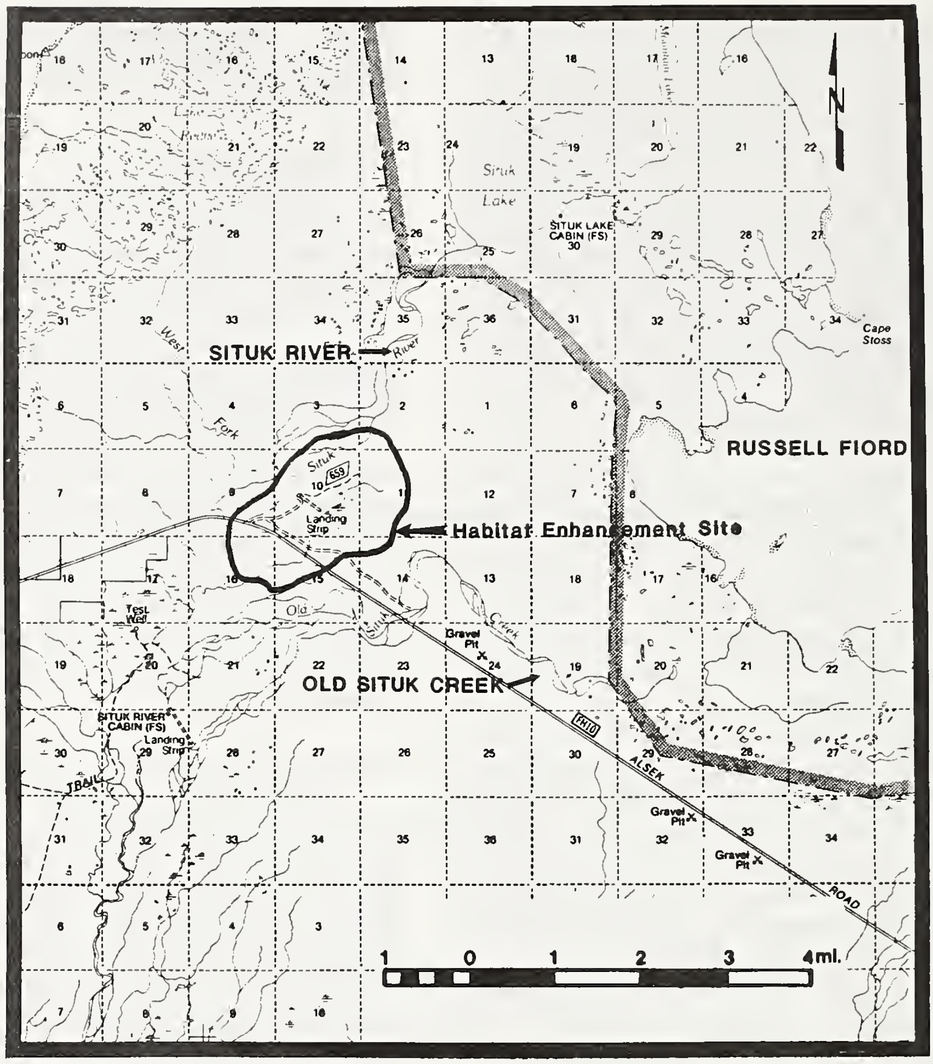


**Figure 5. Proposed Situk River fish habitat enhancement site.**


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# Classification and Inventory of Fish Habitat in the Taku River, Alaska

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A system for classifying fish habitat in large glacial rivers was developed and used in a 1986 study of salmon in the Taku River, Alaska. Twelve distinct habitat types -- 7 within the river channel and 5 off-channel-- were identified on the valley floor (Table 1). Aerial photographs were used to differentiate habitat types by their channel geometry, hydraulic characteristics, and water source. Over 1,900 ha of fish habitat in the lower river, between the Canadian border and the river mouth (29 km), were classified by habitat type and verified with aerial and boat surveys. Random samples of fish abundance and physical characteristics, stratified by habitat type, were used to estimate fish density and habitat quality for each habitat type in the lower river. The two most abundant types (main channels and braids) were in the river channel and made up over 90% of the area. However, the most important habitats for juvenile sockeye, coho, and chinook salmon (Table 2), those with low water velocity and easy access to main channels, made up less than 10% of the area. The total population of juvenile salmon in the lower Taku river was estimated at about one million. Juvenile salmon density in main channel habitats was similar along the entire length of the river (60 km), but species composition changed as sockeye became less abundant and chinook more abundant upstream. Sockeye salmon spawned in many habitat types, keying on specific reaches with good intragravel flow. The habitat classification system described here provided a good framework for identifying juvenile fish habitat in the Taku River and may be applicable to other large glacial rivers.

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**Table 1. Some characteristics used to identify 12 fish habitat types in the Taku River in 1986 and 1987.**

| Habitat Type | Description |
|---|---|
| **River Channel Habitats** | **Habitats within the floodplain.** |
| Main Channels | Large channels (mean >50 m wide and >2 m deep): Swift (mean <30 cm/s) and turbid (>100 NTU). |
| Braids | Regions of many small (mean <10 m wide, <1 m deep), shifting channels separated by unstable bars; Generally moderate velocity (10-30 cm/s) may vary greatly with changes in discharge or gradient; Turbid (>100 NTU). |
| Sloughs | Channels carrying slow moving (<30 cm/s) river surface water. Formed when sediment or debris blocks the head of a main channel; Turbid (>100 NTU). |
| Upwelling channels | Similar to sloughs but clearer (<50 NTU); Few primarily by upwelling groundwater. |
| Channel edges | Margins of main-channels where velocity is <30 cm/s. |
| -Vegetated | -Banks are vegetated and generally are stable. |
| -Nonvegetated | -Banks are not vegetated and may be unstable. |
| Backwaters | Slack water areas created by obstructions (log jams, islands, etc.) in main channels. Velocity <30 cm/s. |
| **Off-Channel Habitats** | **Habitats on the river terrace or at the terrace/floodplain intersection.** |
| Tributaries | Surface flows (stream) originating outside the terrace. |
| Tributary mouths | Transitional areas between tributaries and main-channels. |
| Upland sloughs | Sloughs fed by runoff or seepage from the river terrace (tannic) or by groundwater (clear). |
| Beaver ponds | Ponded areas created by beaver activity. |
| Upwelling basins | Ponded areas formed by upwelling groundwater. |

**Table 2. Use of habitat types by salmon (S=sockeye, C=coho, and Ch=chinook) in the Taku River. Standard error in parenthesis.**

| Habitat Type | Juvenile density by species 1986[1] S | C | Ch | 1987 S | C | Ch | Spawning by radio tagged sockeye[4] (tagged/mainstem spawners) |
|---|---|---|---|---|---|---|---|
| | ------n/100m²------ | | | ------n/100m²------ | | | % |
| **River Channel Habitats** | | | | | | | |
| Main channels | 0 (0) | 0 (0) | 0 (0) | - | - | - | 54* |
| Braids | 5.5 (4.1) | 1.0 (0.8) | 3.4 (1.6) | - | - | - | 0 |
| Sloughs | 35.8 (12.7) | 1.2 (0.4) | 6.5 (5.1) | 15.3[3] (20.3) | 1.3[3] (2.7) | 23.3[3] (35.0) | 0 |
| Upwelling channels | - | - | - | - | - | - | |
| Channel edges | | | | | | | |
| ●Vegetated | 9.0 (5.0) | 1.6 (0.6) | 18.0 (10.0) | 4.1[3] (9.3) | 0.7[3] (0.8) | 24.3[3] (28.7) | 0 |
| ●Non-vegetated | 3.5 (1.3) | 0.5 (0.5) | 1.7 (0.6) | - | - | - | 0 |
| Backwaters | 21.1 (14.2) | 2.9 (2.6) | 5.1 (2.6) | - | - | - | 0 |
| **Off-Channel Habitats** | | | | | | | |
| Tributaries | 1.7 (1.5) | 11.5 (4.2) | 6.7 (4.8) | - | - | - | 14 |
| Tributary mouths | 37.9 (21.3) | 22.7 (19.9) | 6.4 (5.0) | - | - | - | 2 |
| Upland sloughs | 73.4 (45.6) | 58.2 (26.9) | 0 (0) | - | - | - | 12 |
| Beaver ponds | 47.9 (39.7) | 58.5 (27.5) | 0.9 (0.9) | 2[2] | 23[2] | 0[2] | |
| Upwelling basins | - | - | - | - | - | - | 16 |

*Included with main channels

[1]Murphy et al., in press; [2]Thedinga et al., 1988; [3]Lorenz et al., in prep.; [4]Eiler et al., 1988.

# A Preliminary Analysis of Landslide Response to Timber Management in Southeast Alaska: An Extended Abstract

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Soil mass movements (landslides) are dominant processes of soil erosion and sediment transport from hillslopes to stream channels in southeast Alaska. In the early 1960's, before large scale harvest activities, preliminary aerial-photo studies documented the occurrence of 1,374 recent failures greater then 77 cubic meters (100 cubic yards) scattered over the Alexander Archipelago. Failures older then 50 years, which are identifiable by complete revegitation with alder and even-age spruce, were not counted. Failures of less then 77 cubic meters abounded but were not consistently identifiable beneath old-growth forest cover on the only regional photo scales available (1:12000 to 1:15840). These smaller failures were also excluded from the tallies. Within the limits of this sample, most of the failures occurred in unique topographic situations and seemed to be linked directly to initiation by temporary water-table development during high-intensity storms. This has been a continuing process over much of the Holocene Epoch as demonstrated by the common occurrence of talus cones with buried and overturned soil profiles along toe-slopes of most of the stream valleys and widespread occurrence of shallow linear depressions and headwall scarps on middle and upper hillslope sites.

## Landslides in the Undisturbed Environment

Of the natural (undisturbed) failures identified in the pre-1963 survey[1], 87 percent were of the debris avalanche and debris flow type developed on open slopes or interfluves not associated with active stream courses. Almost all these failures originated in shallow, linear depressions oriented perpendicular to the slope contour. These depressions serve to converge ground water flows, destabilizing entrained debris and resulting in repeated landslide activity over geologic time. Once the failure was initiated the resulting debris, a mixture of rock, soil, organic materials, and entrained water, was generally carried to the base of the hillslope as a debris flow. Upon reaching the base of the hillslope, deposition occurred rapidly because of reduced gradients and the buttressing of intervening trees. Only 15 percent of these failures reached perennial streams directly because of the characteristically broad, flattened valley floors produced by glacial scour and subsequent deposition of glacial outwash and mainstream sediments.

The remaining 13 percent of natural failures were debris torrents. These resulting from rapid deposition of large volumes of material from adjacent hillslopes into confining gullies and canyons during periods of storm flow. Although the number of such failures was small, more then 34 percent of the debris torrents cataloged reached low-gradient, viable fish streams and caused clearly identifiable changes in channel morphology. Such changes included alterations in channel flow path, destruction of riparian areas next to the active channel, and movement and redistribution of bottom sediments and large woody debris.

## Assessment of Influence of Terrain Characteristics and Current Management Practices on Landslide Initiation and Hillslope and Channel Alterations

An early analysis of postlogging landslide activity at Hollis on Prince of Wales Island and at Neets Bay and Gedney Pass on Revillagigedo Island (Bishop and Stevens 1964) documented an acceleration rate 4 times the natural rate. This accelerated activity occurred following the first clearcut harvesting on a major scale in southeast Alaska. Roads were restricted to lower slopes and the valley floor in these areas so that road impacts did not affect the analysis. Subsequent work has identified controlling climatic, materials and terrain characteristics and has linked increased landslide activity to alter-

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[1]Austin A. Helmers. Unpublished data. On file with: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Juneau, AK. P.O. Box 20909.

ations in ground-water-surface-water flow regimes and the destruction of stabilizing root systems because of timber harvest (Swanston 1967; 1969; 1970; 1972; Wu and others 1979; Wu and Swanston 1980; Sidle 1984; 1985; Sidle and Swanston 1982). Prominent among these controlling characteristics are (a) occurrence of zones of concentrated rainfall intensity and duration caused by orographic effects of steep mountain slopes and controlled circulation of major storm cells by valley lineaments; (b) slope steepness and landform shape, which determine gravitational stresses, ground water convergence, and length of potential runout; and (c) bedrock and surfacial material composition, which control the location and types of landslides and the strength or resistance of overburden to failure.

What these landslide processes are and how they operate is understood. Unfortunately, limited quantitative data is available on direct management effect and on magnitude of resulting hillslope and channel alterations in southeast Alaska. In 1984, detailed aerial-photo analyses and a field-mapping program of landslides were instituted by the U.S.Department of Agriculture, Forest Service, Pacific Northwest Research Station, Juneau Forestry Sciences Laboratory in cooperation with the USDA Forest Service, Alaska Region, Chatham Area. These studies were designed to address the effects of controlling characteristics and forest-management activities on where landslides occur, how they occur, and their impacts downslope from the point of initiation.

A broad-level photo reconnaissance of landslides occurring over the last 20 years (1963-83) in southeast Alaska provided preliminary Region-wide data on landslide type, frequency, distribution, and general relations to harvest activities. Landslide failure, transport, and deposition zone characteristics were examined and measured in the field at selected sites to provide further information on size, quantity of sediment temporarily stored on the slope, and quantity of sediment delivered to the valley floor and stream channel in harvested and nonharvested areas.

*Regional Photo Reconnaissance*

The principal part of this study segment involved the location, typing, and terrain characterization of all landslides in southeast Alaska greater then 77 cubic meters (100 cubic yards) that have occurred since 1962. The sample restrictions used in the Helmers study (see footnote 1) were applied here because of similar photo scales and resolution limitations. Map transfer of all identified failures was made to standard USGS 15-minute quadrangle maps at a scale of 1:63360 by using a zoom-transfer stereoscope. Exact location and scale reduction were difficult because of the basic inaccuracies of the small-scale topographic maps; care should be taken when this data is used for site-specific assessments. As part of the inventory process, slope gradient and elevation of the failure zone and the area of initial failure were estimated from the aerial photos and topographic maps by use of parallax bar and hand scaling. Estimates were also made of length of slope run (distance from failure site to deposition site). No estimates of the area of deposition were made because of the difficulty of defining zone boundaries on all but the most recent failures.

A total of 1395 discrete landslides greater then 77 cubic meters in initial release volume were identified and mapped. Because none of these were identifiable on 1962 photos, each was assumed to have occurred within the 20 years from 1963 to 1983, a period essentially bridging the development of large-scale clearcutting in southeast Alaska. Of this total, 118, or about 9 percent, occurred in clearcut areas or were directly associated with timber harvesting. This clearly reflects the overwhelming dominance of landslides as a long-term natural erosion process and the relatively small portion of the total land area of the Panhandle directly involved in timber harvest (about 3 percent). Most of the failures occur in terrain situations that are highly unstable (steep gradients, hillslope depressions) or are difficult to access and have therefore been avoided in operational planning. If we consider these landslides in terms of their rate of occurrence per land area, the effects of timber management become more apparent. The rate of occurrence of landslides in undisturbed areas over this 20-year period (38,642 square kilometers) is 0.002 landslides $km^{-2}$ $year^{-1}$. The rate of occurrence of landslides in clearcut areas over this same time period (1,070 square kilometers) is 0.01 landslide $km^{-2}$ $year^{-1}$, a fivefold increase.

On a region-wide basis, and no regard for management impacts, 77 percent of the landslides are of the debris avalanche and debris flow types that involve the movement of a water-charged slurry of soil, rock, and organic debris down shallow gullies and hillslope depressions. The remaining 23 percent are debris torrents that are similar in character to debris flows in the initiation zone but identified by larger size, longer runout on the valley floor, and general confinement to deeply incised gullies and canyons. About 3 percent of all failures counted reached known anadromous fish channels. Sixty two percent of these landslides develop on slopes having an average gradient in excess of 75 percent. An additional 30 percent develop on slopes that have an average gradient between 56 percent and 75 percent. They also appear to occur within a limited range of

elevations, with 72 percent of all failures occurring below 400 meters.

There are significant differences in the general character of landslides in cut and uncut areas. Paired t-tests indicate that, as a general rule, landslides in uncut areas are significantly larger, occur at higher elevations, develop on steeper gradients, and tend to travel greater distances. This is, in part, a reflection of more stable conditions over broader areas of undisturbed hillslope. Larger or more intense triggering events are needed to initiate a failure, and failures tend to develop where maximum stress characteristics (minimum strength) such as steeper slopes, shallower soils, and more rapid water table developments occur. Timber harvesting also tends to occur at lower elevations and on less steep slope gradients because of operational and management restrictions.

There are also significant differences in landslide characteristics between the North Tongass and the South Tongass National Forests. This division is used primarily to differentiate between geographic areas which are believed to have significant climatic and terrain differences: more intense storms, colder temperatures, and larger areas of steep terrain occur on the North Tongass. The North Tongass National Forest includes both the Chatham and the Stikine Areas. The South Tongass is composed of the Ketchikan Area. Paired t-tests of landslide characteristics in these two areas indicate larger failures and greater transport distances on the South Tongass. Failures also occur at higher elevations on the South Tongass. There is no significant difference in slope gradient of the failure zone. The greater mean failure size on the South Tongass seems to be related to geologic conditions favoring larger initial landslides associated with bedrock cliffs and rock failures along bedding and fracture planes underlying the shallow overburden.

*Field Sampling Phase*

This portion of the study involved detailed mapping and sampling of landslides from the headwall to the toe to define average initiation, transport, and deposition zone characteristics. Sampling was carried out in both cut and uncut areas and on both the northern and southern portions of the Tongass to ascertain any gross differences in these characteristics. Because of high management interest and ease of logistics, sampling was concentrated in areas that had active harvesting and a well-developed road network. These areas encompassed the east side of Chichagof Island and central and northern Prince of Wales Island. A total of 164 landslides were mapped; 71 were mapped on the North Tongass National Forest at Kennel Creek, Corner Bay, Crab Bay, Sitkoh Bay, and the False Island area. The remaining 93 were mapped on the South Tongass National Forest at 12-Mile Arm, Harris River, Maybeso Creek, Staney Creek, Shaheen River, Luck Lake, El Capitan Passage, Red Bay, Alder Creek, and Calder Bay. All these landslides were of the debris avalanche and debris flow types.

Along with quantitative measurements of failure and flow characteristics, notations of microtopography, parent material type, and aspect were made for each initiation site. No buried soil or volcanic ash lenses were noted during the field survey. In unlogged areas, most landslides (90 percent) originated in shallow swales or on the open slope outside of definable depressions. Only a small number of incised gullies were directly involved in initial failure (10 percent of sample). In logged areas, the number of incised gullies involved in initial failure is substantially increased (31 percent of sample), possibly reflecting the increased disturbance of gully walls and loading of the gully floor with soil and organic debris during yarding operations. The distribution of parent materials in relation to landslides reflects the regional distribution of parent materials and seems to be independent of management activities. The dominant aspect of failure sites in unlogged areas is westerly. No failures on northern exposures were observed, but this could be an artifact of the north-south trending valleys and the location of most accessible sites on east- and west-facing slopes. In logged areas, dominant aspects were east and south.

A comparison of initial size of failures, transport distances, erosion in the transport zone, and volumes of deposited materials at the base of the hillslope and delivered to channels supports the findings of the regional survey and indicates that landslides are larger and potentially more damaging on the South Tongass then on the North Tongass. Similar relations are indicated between logged and unlogged areas with failure size, length of transport, quantities deposited, and channel impacts greater in unlogged then in logged areas. All but two of these variables on a regional basis (southeast Alaska) are significantly different. Regionwide, there are no statistically significant differences between slope gradient and mean length of disturbed channel.

On a sub-Regional or area basis (North Tongass, South Tongass) these relations are not quite as clear. On the North Tongass (primarily East Chichagof Island), only transport distance and elevation at the point of initiation are significantly different, with failures occurring at higher elevations and landslide debris traveling greater distances in unlogged areas. In contrast, on the South Tongass (primarily Prince of Wales Island) failure

size, transport distances, erosion in the transport zone, and volumes of deposited materials are all significantly greater in unlogged areas. Only failure-zone gradient, mean volume in channel, and mean volume stored on slope are not statistically significant.

Correlation analyses of paired variables recorded during the field sampling phase provide additional insight on the character of landslides and their response to terrain and vegetation-cover conditions. For example, very high correlations between volume of landslide deposits and volume of material eroded from the transport zone coupled with the poor level of correlation ($|R|<0.50$) between failure volume and volume of landslide deposits at the base of the slope on both the North Tongass and South Tongass and in logged and unlogged areas ($|R|>0.95$) suggest that regionally, the quantity of landslide debris reaching the base of the slope is heavily dependent on mobilization of debris along the transport path.

The size of the failure Regionally (expressed as the width of the failure zone) is also highly correlated with transport zone width, thereby suggesting that most failures and subsequent transport paths are controlled by pre-existing gullies or linear "zero-order" basins.

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# Low Tire Inflation Pressure -- A Solution to Breakdown of Road Surface Rock

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***Abstract.*** In many areas in Southeast Alaska the rock borrow material is too weak to provide a stable road surface to support truck haul. The road surface tends to rut and the rock continually breaks down with heavy repeated wheel loads combined with wet conditions. This process breaks the gravel down to fine silt and clay size particles which are bladed into the ditch and is a continual source of material contributing to stream sediment. It was determined that using radial tires with low tire pressure compacts and "seals" the surface when poor quality rock borrow material is encountered. This has resulted in a large economic savings and should be an effective tool to decrease future rock quality problems.

The Forest Service has been studying the effects of reducing tire pressures on road construction and log hauling vehicles since 1974. Early studies indicated that there could be substantial benefits, therefore the Forest Service began a series of field test projects in the 1980s. Based on test projects completed thus far, there appears to be a number of potential benefits including reduced road maintenance, less truck wear, and reduced driver fatigue. Test projects have been completed in various parts of the country to obtain more specific information for evaluation purposes. Also, a test track was recently constructed in Vicksburg, Mississippi that will continually operate trucks with variable tire pressures on various types of controlled pavements. On the Tongass National Forest one low tire inflation project was successfully used to avoid costly changes in construction costs. This report outlines the findings and provides a limited amount of testing and observations that indicate a reduction in tire pressure will reduce the amount of material available for stream sedimentation.

## Observations and Findings

In the Fall of 1987 the Forest Service was experiencing problems with rockborrow material being used to construct timber access roads for the Toncan Timber Sale. The sale is located about 20 miles southwest of Petersburg, Alaska, on Kupreanof Island. Even though the material passed our Timber Sale Standard Specifications the material was not performing well enough to support construction hauling vehicles used to build the road. The rock is a Phyllite that is similar to rock that we have experienced problems with in the past. Materials testing for rock quality is summarized in table 1.

**Table 1. Material Test Results for rock borrow material for Toncan Timber Sale.**

| | Los Angeles Abrasion | Durability Index (AASHTO T 210) Coarse | Durability Index (AASHTO T 210) Fine | Sand Equivalent (AASHTO T 176) |
|---|---|---|---|---|
| | % | % | % | % |
| Specification | 40 maximum | 35 minimum | 35 minimum | 35 minimum |
| Test Result | 29 | 41 | 73 | 40 |

Even though the material passes the specifications we were aware that rock quality problems would occur. There was a high priority for the field investigations prior to construction and although possible problems were expected there was not any higher quality rock found in the immediate area. When the Fall rains started the rock broke down during rock haul on the newly constructed road to the point where trucks were dragging axles in 1/2 meter deep ruts. Gradation tests were conducted on the rock borrow material when the

rock was initially placed on the road surface and again after 7 days of rock haul. The purpose was to determine specifically how much mechanical breakdown was occurring. Results are summarized in Table 2.

**Table 2. Material gradation before and after truck haul.**

| | Finer than 7mm (3 inch) | Finer than #4 sieve, 4.7mm (sand size) | Finer than #200 sieve, 0.074mm |
|---|---|---|---|
| | % | % | % |
| Before Haul | 100 | 17 | 3 |
| After Haul | 100 | 30-50 | 17 |

As stated above similar rock quality problems have occurred in the past. The solution is to blade the decomposed rock off the shoulders and into the ditches and then overlay with a higher quality rock from the nearest known source. It was calculated that it would cost the Government $577,300 in design changes for additional materials production and haul costs. Through technology transfer our engineers considered the possibility of using lower tire pressure to continue to haul on the decomposed rock. Our problems seemed much more extensive than other projects where lower tire pressures were used, but because of the relatively low cost it was decided to go ahead and see what would happen. Since lowering tire pressures is somewhat new, especially in Southeast Alaska, it was necessary to determine the size of tires and rims that could be used. The tire size selected was 1200Rx24 and because of the lug spacing on the Hayes Trucks special rims were fabricated for this tire size. The total cost of the tires tubes and rims was $49,400 for four trucks, much lower than the alternative of overlaying the road with higher quality rock. It was decided that constant tire pressure would be used rather than a central tire inflation system. The cost for a variable tire pressure system is between $1,000 and $1,500 per axle, installed, and these systems are still in the development stage for practical use. Based on experience on previous projects, and tire manufactures recommendations, the optimum tire deflection is 20% to 23% of the unloaded tire. It was decided to set the tire pressure using the deflection of the loaded trucks, lower tire pressures for unloaded trucks would have provided an additional benefit. If the unloaded trucks did cause excessive road damage an airing station could have been added on the project. Final pressures varied between the different types of trucks, and the front and rear wheels, ranging from 2.9 to 4.3 kilograms per square centimeter (42-62 psi.).

In early December, 1987 rock haul was resumed using the newly installed tires utilizing lowered pressures. Positive results were immediately observed. Instead of breaking down the rock the tires tended to compact the surface and rock decomposed only in the top few centimeters below the road surface. Where the road was wide enough the trucks could vary their wheel path so that the entire width of the road would be compacted evenly. Where the road was narrow and was built on a grade it was more difficult to vary the wheel path and ruts did form, but the maximum depth of rut was less than 10 centimeters even after several weeks of rock haul. The contractor was pleased with the results and also equipped their log haul vehicles with radial tires to take advantage of the reduced maintenance of the road surface.

The road contractor continued to haul for several weeks before winter snow prevented continued work. The contractor then started work again in March, 1988. When haul started the road began to deteriorate and it appeared that the same problems would develop that originally occurred. A check on the tire pressures revealed that one of the trucks was operating at normal high operating pressure on the front axle, at about 6.3 kilograms per square centimeter. When the pressures were lowered, the hauling tended to "heal" the surface again until the construction was completed.

## Conclusions and Recommendations

On the Toncan Timber Sale low tire pressure has not only saved the Forest Service over $450,000, but has also reduced the amount of fine silts and clay that

potentially enters local streams. There have been numerous projects where the same type of rock breakdown occurred and we are very pleased that there is now a solution for future projects. There are many miles of existing roads where surface breakdown is continually occurring and generating fine particles which can result in an increase in stream turbidity. Low tire pressure could be an economical means of reducing road maintenance and at the same time reduce the source of potential stream sediments.

When making decisions on the use of lowered tire pressures or central tire inflation, care should be taken to select the proper tire and rim size. In some cases central tire inflation is necessary, and proper installation and maintenance is important. A number of personnel in the Forest Service could be consulted by anyone desiring information on low tire pressure options. Start by contacting Paul Greenfield at the San Dimas Technology and Development Center, telephone (818) 332-6231.

Further studies could be conducted to determine if low tire pressure is effective at reducing material entering streams. Streams adjacent to roadways could be monitored before and after using low tire pressure.

# Channel Response to Mass Wasting in the Queen Charlotte Islands, British Columbia: Temporal and Spatial Changes in Stream Morphology[1]

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***Abstract.*** A paired watershed study is being used to compare stream channels with various ages of mass wasting disturbance with similar channel types in undisturbed basins. In year 1 of a 4 year program (1988), approximately 27 km of stream channel were inventoried, including a wide range of stream sizes and debris torrent ages from 1 to 150 years. Morphological parameters of relevance to fish habitats were the focus of the field surveys. A case study presented here.

A fundamental consequence of debris torrent inputs to stream channels is the establishment of sediment wedges associated with debris jams. Specific sedimentological, morphological and hydraulic changes occur upstream and downstream of the jams. The sediment wedges are of two basic types, vertical and lateral. The location, size and function of each type of jam controls morphology and their distribution along the water course influences the spatial adjustment of the channel. The integrity and longevity of the debris jams control the temporal response of the channel. Initial results indicate that severe morphological alterations persist during the first decade following debris torrenting, but the channel begins to develop more normal characteristics during the second and third decades. The morphological nature of stream channels 30 years after disturbance begins to resemble undisturbed channels.

The influence of landslides on stream environments has been a concern in the Queen Charlotte Islands for many years. Studies completed in the first phase of the Fish/Forestry Interaction Program (FFIP 1) attempted to quantify the magnitude of the problem and show that increased sediment loads derived from hillslope processes lead to many morphological and fish habitat changes along the stream system. Morphological alterations include a general reduction in channel complexity with reduced depth, width and sediment texture variability, less stable lateral and longitudinal profiles, diminished pool area and more pronounced riffles (Hogan, 1987). Fish rearing, incubation and spawning habitats are also impaired (Tripp and Poulin, 1986 a, b and c).

A key consideration not adequately resolved in the FFIP 1 studies is the importance of time as an independent variable influencing channel conditions, both in terms of morphology and habitat. This factor confounded certain results presented by Hogan (1986) and probably some of those of Tripp and Poulin (1986 b). For instance, in situations where a watershed had a history of hillslope failures, and it had also been logged, it was not possible to determine conclusively which factor (natural slope instability or logging and related activities) was primarily responsible for the documented channel change. In other cases where the watershed had never been logged, but it had evidence of old landslides entering the stream channel, no rigorous criteria were followed to determine how old the landslide had to be before it was grouped with non-mass wasted streams. Also, although the presence or absence of mass-wasting was usually considered, the actual timing or size of the event was not evaluated explicitly in any stream study. By contrast, in almost all FFIP 1 studies the amount, type and timing of logging was included as an important factor in the study design. Difficulties in identifying revegetated landslide deposits and problems associated with determining the deposit ages are probably the reasons why landslide histories have been largely neglected in past stream studies.

Studies in other geographic areas have tried to evaluate the channel response to landslide deposits entering the stream and to relate these to fish habitats. Sullivan et al. (1987) summarize many of the studies conducted in Northern California, Central Idaho and the Western Oregon Cascades (all rivers are relatively large compared to the Queen Charlotte Islands study streams). They show that in most cases the channel bed aggrades, bank stability is reduced as the channel widens and pools are infilled. In extreme cases, large sedimentation zones with extensive braiding occur, as documented in the Queen Charlotte Islands by Roberts and Church (1986). Associated habitat changes include increased proportions of fine grained sediment in spawning areas, reduced rearing habitat, increased dewatering during low flow periods, reduced food sources with loss of tree canopies and changed water temperature regimes.

Sullivan et al. (1987) also review channel recovery rates and processess in four research areas of the United States. They show that the time required for the stream to recover to pre-disturbance conditions varied from 5 to over 60 years. The recovery time depends upon input

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[1]Fish/Forestry Interaction Program, Phase II

sediment characteristics (location along the stream system, amount and particle size distribution) and the form and structure of the riparian zone. Therefore, streams respond in specific ways to both natural and logging related sediment inputs and the respose time of a stream system can be relatively rapid or prolonged for many decades.

The temporal response of stream channels to landslides has resource management implications. From a forest management perspective, it is important to realize that large sediment wedges, as described by Roberts and Church (1986), occur naturally in some basins and are a result of mass-wasting and subsequent channel adjustments and are not logging related. The potential consequences of logging slopes already contributing sediment to large wedges must be evaluated. Without a better understanding of the channel response processes and rates it is not possible to evaluate the long term impacts of forest operations on the channel.

The implications for fisheries management are also important. Stream channels in the Queen Charlotte Islands exhibit a wide range of morphological characteristics. The natural variablility of these must be known when evaluating potential or actual impacts. Further, if landslides deliver large volumes of sediment to the stream, specific habitat changes will occur at the site. The sediment may then be moved downstream in a wave, or pulse, and this can progressively impair habitat for various lengths of time. The duration, and relative severity, that habitat is degraded is unknown. Finally, it is very difficult to attempt habitat rehabilitation when little is known about how the channel adjusts over time. Channel stabilization and rehabilitation structures should be designed to perform well over the long term, but designs are usually based on the channel condition at one point in time. A better understanding of the spatial and temporal nature of a stream channel's response to altered sediment supply characteristics is required for this application.

This paper serves two purposes: a) it introduces the goals and objectives of the second phase of the Fish/Forestry Interaction Program (FFIP II) in British Columbia and; b) it presents prelimimary results from Year 1 of the FFIP II stream channel morphology studies.

The intent of the long-term FFIP II project is to better understand the processes and rates of channel response in order that a classification system can be developed that is focussed on channel sensitivity to disturbance. The specific ojectives of the FFIP II study are:

1. To determine diagnostic criteria of the nature and extent of channel response to mass wasting sediment delivery.
2. To identify and describe the factors controlling rates of response to sediment loading in channels.
3. To incorporate the results into a classification system and methodology for predicting the probable response of a channel to a given mass wasting input including downstream propagation and recovery.

Only objectives 1 and 2 will be considered in the present paper. Preliminary results from a single watershed are presented here to illustrate the field methods and the character of the results.

### Study Design and Environmental Setting

The FFIP II study design incorporates a paired watershed approach. This involves comparison of drainage basins with similar biophysical characteristics (climate, geology, soils, vegetation and morphometry) but different slope failure and logging histories. The basic approach is detailed in Hogan (1986) but is expanded here to include the substitution of space for time. This enables the study of channels that have been disturbed for time periods ranging from recent to very old (eg. 150 years ago) in addition to those that have never been disturbed by mass wasting or logging activities. "Never" in this case is defined as a watershed that shows no evidence of landslide activity on any of the available air photographs--large landslides with ages exceeding 150 years can usually be detected. The condition of channels disturbed by landslides that occurred one year ago, 2 years ago, 5 years ago, 50 years ago, etc. are to be compared to non-disturbed channels in biophysically similar watersheds. This approach enables a very wide range of stream conditions (response) to be evaluated and thereby provide boundaries around the morphological variability of natural stream systems.

The study involves four steps:

- selection of suitably paired undisturbed, disturbed, and logged watersheds;
- comparison of fundamental morphological units in each watershed (based upon longitudinal profiles);
- comparison of detailed morphologic and hydraulic features in each watershed (based upon representative reaches); and
- combination of basin, channel and reach scale study results to develolp and verify a stream classification system stressing a channel's sensitivity to disturbance.

The linkages between each step is shown in Figure 1.

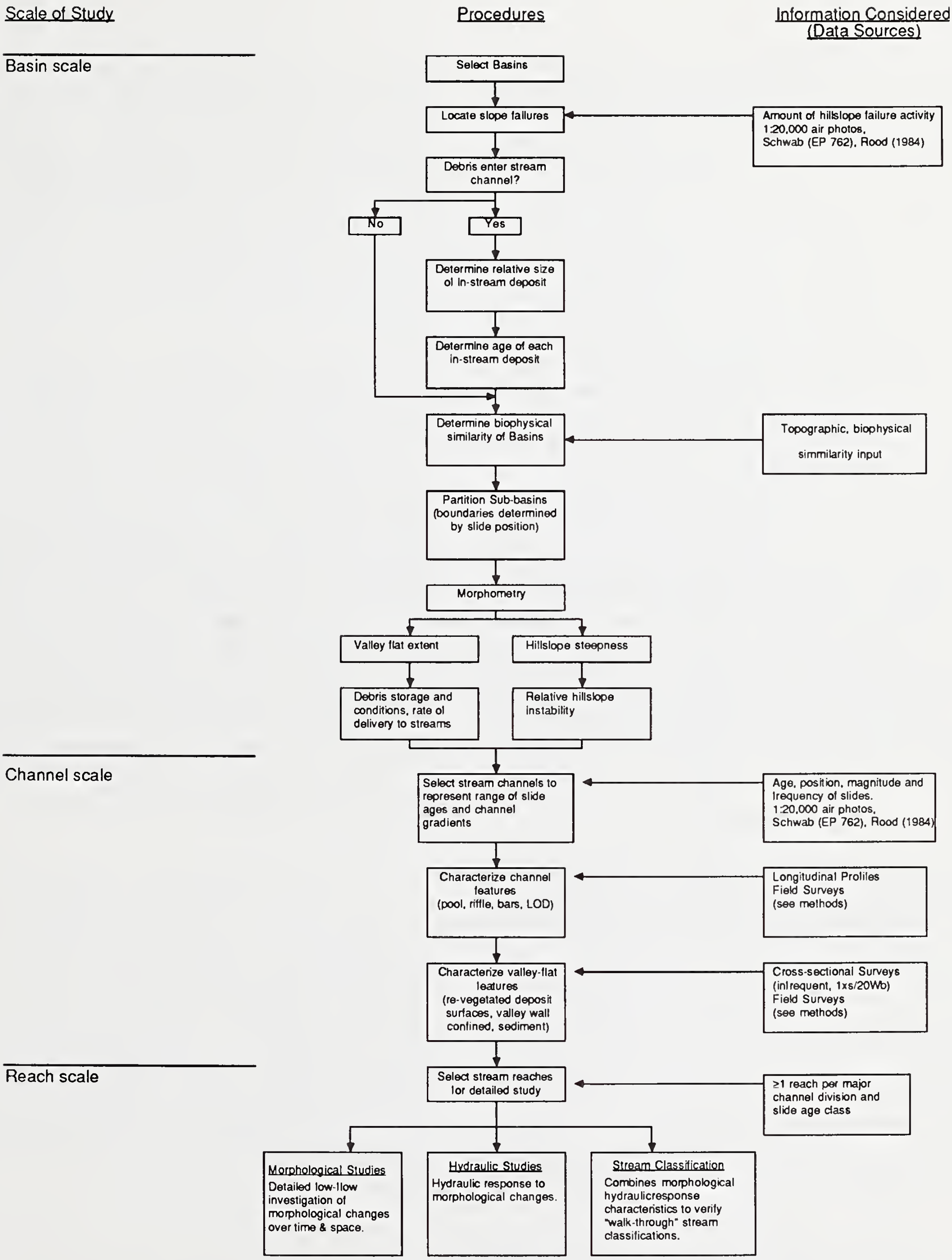


**Figure 1. Channel response study procedures.**

Within main study watersheds with generally similar biophysical conditions (eg. climate, vegetation and soils) but with minor morphometric differences (eg. overall drainage area), smaller sub-basins were delineated depending upon the location, size and age of landslides. Channel and reach scale studies were conducted within these sub-basins and compared with the most morphometrically similar sub-basin.

Four general areas will be studied over the course of this project. These coincide with regions currently being investigated by Schwab[1] because his work includes inventories of landslide location, age, type and size. This provides the relevant landslide histories required for the channel response study. The four general areas and the case study watershed to be considered here are shown in Figure 2. Riley Creek is presented as a case study in this paper.

Riley Creek has a drainage basin area of 28.3 km² and terrain relief of 840 m. It is within the Skidegate Plateau physiographic region and is comprised mainly of weathered volcanic rocks (Sutherland Brown,1968). The watershed receives in excess of 3600 mm of precipitation each year and the main tree cover is western hemlock and Sitka spruce. A total of 4 km² (14%) of the watershed was logged during the late 1970s and the basin has the highest landslide frequency, at 5.97 events per km², in the Rennel Sound study area (Rood, 1984). The second highest frequency in the area is 3.38 events per km².

## Methods

Detailed longitudinal profiles were surveyed over extensive channel lengths to document morphological conditions in channels with different ages of disturbance. The profiles were surveyed with an automatic level and stadia rod, and distances were measured with a surveyor's hip chain. Several measurements were made at set intervals along the channel. The procedures followed and equipment used are summarized in Table 1. The survey interval of 1 bankfull channel width (Wb) was selected objectively from regional drainage basin area-channel width relations for unlogged and non-mass wasted watersheds. This approach enables objective analyses of channel characteristics and avoids difficulties inherent in determining the correct interval (channel width is dependent upon time since disturbance). Other morphological features (eg. breaks separating pools, glides, riffles and runs) were added as supplemental survey points. These were identified in the field by their topographic, sedimentological and hydraulic characteristics as defined by Keller and Melhorn (1973) and Sullivan (1986). Long lengths of channel, in excess of 100 Wb, were surveyed in all study streams. The valley floor width was measured at the 5Wb interval. General changes in riparian vegetation size and species were noted.

In addition to the measurements made at each survey interval, all LOD steps and debris jams were also surveyed. Debris jams are particularly important and were described in additional detail. A jam is defined as a major accumulation of debris (either currently or over the last decades--that is, remnants are still evident) that alters(ed) sediment transport downstream (stored sediment is evident). The classification is intended to describe the current function of the jam in terms of how it influences sediment transport and channel stability. The debris jam classification developed for this purpose is given in Table 2. This scheme is presented in full because it will be shown that debris jams are critical in controlling both the spatial and temporal adjustment of these stream channels. Debris jam characteristics will also play an important role in the stream classification system to be developed as an end product of this project (FFIP II ojective 3, as stated above).

## Results and Discussion: A Case Study

Results from 7 km of Riley Creek are presented here. This sub-set includes a wide range of channel conditions (150 year old landslides, more recent debris torrented channels, no evidence of mass-wastage events) and gradients in both logged and non-logged areas. The conditions discussed in the present paper are considered to be representative of typical streams in the Queen Charlotte Islands. Further work is required before strict comparisons can be made between channel types (various land-use activities and hillslope failure histories).

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[1]Schwab, J. W. In Progress. The magnitude and frequency of mass wasting events in the Pacific North Coast Region. Ministry of Forests, Prince Rupert Region, Forest Sciences Section, Smithers, B. C., Canada, Experimental Project No. 782.

**Table 1. Field methods**

| Procedure | Equipment,units | Method and Notes |
|---|---|---|
| **Longitudinal Profile** | | |
| Thalweg | Auto Level,stadia | Elevations by difference |
| Distance | Hip chain,m | Distance along thalweg, read by rodman |
| Water surf. width | Fiber tape,m | All channel widths (main, secondary and side/back channels) measured (± 0.05m) at the 5Wb interval |
| Water depth | Stadia,m | Depth of water at the thalweg, read by the rodman |
| Bar Surface | Auto Level,stadia | Elevation of bar surface at each interval |
| Bank top | Auto Level,stadia | Elevation of overbank surface was sighted whenever possible |
| Bankfull width | Fiber tape,m | Measured to nearest 0.1m at the 5Wb interval; distinquished by vegetation breaks primarily, bank profile and materials noted |
| **Large Organic Debris** | | |
| LOD quantity | Ranking | Groups of LOD classes based on diameter, length and number of pieces for every Wb length of channel: |

| Rank | Diameter,m | Length,m | No. of Pieces |
|---|---|---|---|
| 1 | ≤0.1 | 1-5 | ≤2 |
| 2 | 0.1-.03 | 5-10 | 2-3 |
| 3 | 0.3-0.7 | 10-15 | 4-7 |
| 4 | 0.7-1.2 | 15-20 | 7-10 |
| 5 | >1.2 | >20 | >10 |

| Procedure | Equipment,units | Method and Notes |
|---|---|---|
| LOD orientation | Ranking | Primary orientation ranging from perpendicular to parallel to the flow |
| LOD function | Ranking | Basic description of LOD sediment trapping and scouring action (lateral or under scour, LOD step, etc.), also if wad attached |
| **Surface sediment and Morphology** | | |
| Largest sediment | Hand tape,mm | Visual inspection of the bar surface and the largest stone transported by flood flows was estimated and measured (b-axis), large blocks dropped from local bedrock banks were not included in the largest sediment class; a qualitative rating was also assigned to the local areal sediment texture at each interval. |
| Morphology | Descriptive | Each interval point was identified as a pool, riffle, cascade or rapid (according to Sullivan, 1986) whenever possible--often just called a riffle at high flows |

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Additional notes include details regarding bank materials and profile, occurrence of bank erosion and apparent cause (logging, debris, etc.) and any other feature of interest.

**Table 2. Debris Jam Classification**

| Jam Feature | Characteristics | | Rank |
|---|---|---|---|
| **Jam Age** | Very young; primarily new trees (bark, branches, etc.), includes new debris from upstream and upslope, apparently formed during the last major storm event. No nursed trees. | | 1 |
| | Recent; less than 10 years, trees have some bark and few branches, nurse trees (usually alder) are less than 5 m high, nurse trees are aged in the field (cut and rings counted) | | 2 |
| | Moderate; nurse trees between 10 and 30 years old, aged by visual inspection (see following classification of vegetation)or by increment cores | | 3 |
| | Old; moss on debris, nursed trees 30- 50 years old | | 4 |
| | Very old; nursed trees >50 years old, debris has no bark or branches | | 5 |
| **Jam Integrity** | | | |
| | Very solid; compact, strong wood (no rot), v. large debris (largest LOD pcs have diam ≥ 1Db and lengths ≥ 1Wb), v. stable and large anchors present (eg. wad, bedrock, etc) | | 1 |
| | Solid; compact, strong wood but smaller LOD than in Rank 1 (ie. largest pieces have diam ~1/2Wb and lengths ~ 3/4 Db), and less well anchored | | 2 |
| | Moderate; less compact (spces between LOD pieces), smaller and more mobile LOD pieces | | 3 |
| | Weak; predominantly small debris pieces, large debris pieces generally rotten and jam has poor or precarious anchor (moved at high flows) | | 4 |
| | Very Weak; very small debris pieces, no anchor and jam is in transition (hard to determine if a jam exists) | | 5 |
| **Jam Span** (lateral extent) | | | |
| | Complete; | jam completely crosses the channel and forms a dam, water flows over the top | 1 |
| | Incomplete; | 3/4 ≤ span < 1 Wb, water flows around one end or through mid section of jam | 2 |
| | | 1/2 ≤ span < 3/4 Wb, water flows around one end, etc. | 3 |
| | | 1/4 ≤ span < 1/2 Wb, water flows around one end, etc. | 4 |
| | | span ≤ 1/4 Wb, water flows around one end, etc. | 5 |

**Table 2 (Continued).**

| Jam Feature | Characteristics | | Rank |
|---|---|---|---|
| **Jam Height** (vertical extent or depth) | | | |
| | Full; jam is as high or higher than the local bank height | | 1 |
| | Not Full; | 3/4 - full bank height | 2 |
| | | 1/2 -3/4 bank height | 3 |
| | | 1/4 -1/2 bank height | 4 |
| | | <1/4 bank height | 5 |
| **Sediment Storage** (upstream of jam) | | | |
| | Full; the channel zone is completely full of sediment (ie. sediment is filled to the top of the jam and extends completely across the channel, sediment extends upstream as a function of the channel gradient, or until the next debris jam | | 1 |
| | Not full; | <1/4 of the sediment evacuated (compared to full--as a function of the channel width, and jam height) | 2 |
| | | 1/4 - 1/2 of the sediment removed (eg. partially full) | 3 |
| | | 1/2 - 3/4 of the sediment removed | 4 |
| | | > 3/4 or all sediment removed | 5 |
| **Jam location** | | | |
| In-channel | on one side of channel only | | RB,LB |
| | mid channel (open on sides) | | M |
| Along channel | at a bend | | B |
| | at a bedrock knob or outcrop | | R |
| | at a wad or tree stump anchor | | W |
| **Jam shape** | | | |
| | Perpendicular to channel | | L |
| | Diagonal to channel | | |
| | Parallel to channel | | II |
| | Arched, apex downstream | | V |
| | Arched, apex upstream | | A |
| **No. of channels** (includes flood channels) | | | |
| | One | | 1 |
| | Two | | 2 |
| | Three | | 3 |
| | Braided | | 4 |
| | Braided | | 5 |

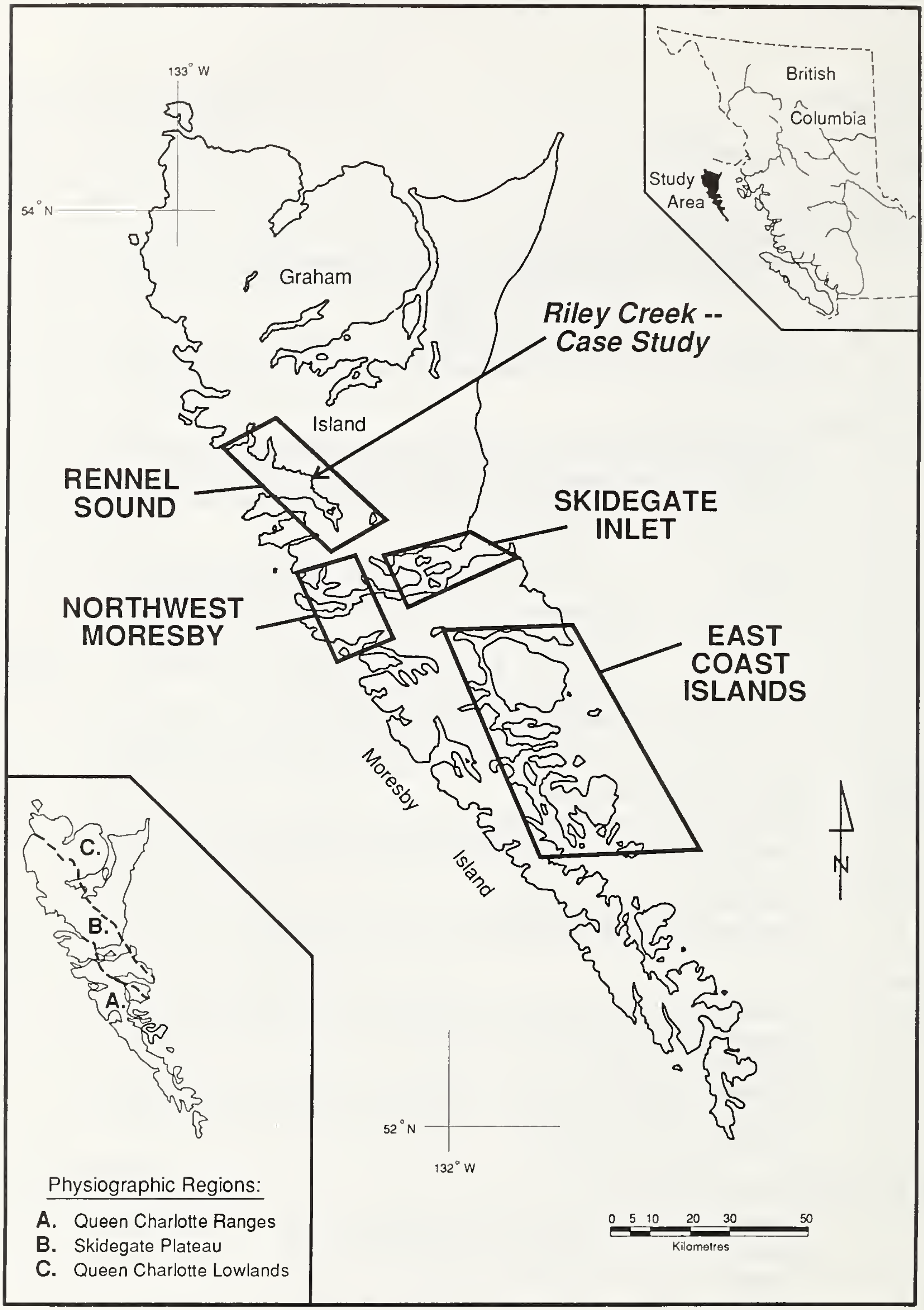


Figure 2. Channel response study area, including the location of the Riley Creek case study.

The longitudinal profile for a continous section of channel in Riley Creek is shown in Figure 3. This plot illustrates several important points. First, the profile is influenced strongly by debris jams. This is seen by the extensive sediment accumulations upstream of the jams (zones lying above the smooth line drawn through the data points--the smooth line is a computer generated second order polynomial placed simply to make visual inspection easier). Second, there are two distinct debris jam types. These are classed as vertical and lateral jams. The different types are related to valley bottom conditions and their diagnostic characteristics are considered in Table 3. They both appear to produce large sediment wedges upstream but their longitudinal extent is different.

**Table 3. Large scale In-channel sediment storage sites (wedges).**

| | Vertical Debris Jams | Lateral Debris Jams |
|---|---|---|
| Location: | Laterally confined valley walls | Valley flat, not confined |
| Size: | Width ~ 2 * channel width<br>Height ≤ 10 * channel depth | Width ~ 10 * channel width<br>Height ≤ 2 * channel depth |
| Jam Arrangement: | Longitudinal series of debris piles | Lateral series of dispersed debris |
| Associated with: | Major keystones (tree, root wad, bedrock, bend, etc.) | Series of inter-connected debris jams. |

In Figure 3b the spatial extent of vertical jams is evident. If many vertical jams exist in close proximity to one another the overall result is a major sediment wedge. The total longitudinal extent of sediment accumulation can in this case match that of a lateral debris jam. Vertical debris jams are often developed at the terminus of debris torrents and this is evident in the present data. The cause of horizontal debris jams is not as evident. It appears that they may be a result of coalescing fluvial and debris torrent fans on a wide valley flat so that the channel shifts laterally across the valley. The channel migrates laterally around fans building out onto the valley flat. Another possibility is the progressive filling of sediment upstream of a major landslide that blocks the downstream transfer of sediment. In either case, the temporal response of the lateral wedge should be different than that of the vertical wedge. It is too early in the present study to consider these aspects of the lateral jam. The remainder of this paper deals with vertical jams.

A third aspect of the longitudinal profiles shown in Figure 3 are the smaller channel bed undulations. Previous studies in the Queen Charlotte Islands, and many others, show that these smaller scale pools and riffles are frequently associated with large organic debris (LOD). Hogan (1987) discusses LOD characteristics in these streams and concludes that LOD is an important factor controlling the morphology of these small coastal streams. LOD exerts considerable influence over the bed elevations shown in Figure 3b.

Debris jams resulting from torrents cause substantial sedimentation upstream of the jam, but between the jams, individual LOD pieces play an important role in producing a complex and diverse channel morphology. Therefore, LOD operates at two scales (at least); large scale jams and small scale individual LOD pieces. The spatial distribution of vertical debris jams along the channel must, then, have important implications for stream morphology. The jam-to-jam spacing distances are given in Figure 4. Vertical debris jams are spatially prevalent. The distribution is strongly skewed to the left indicating that the distance between jams is relatively short, averaging one jam per 8 channel widths.

Although debris jams are spatially important, it is clear in the field that they are different than other in-channel blockages, such as rockslides, that create essentially permanent dams. Debris jams begin to breakdown over time. The debris pieces rot, are broken into smaller sizes and are moved by floods. The longevity of each jam influences its temporal role in controlling channel morphology. This aspect is considered in Figures 5

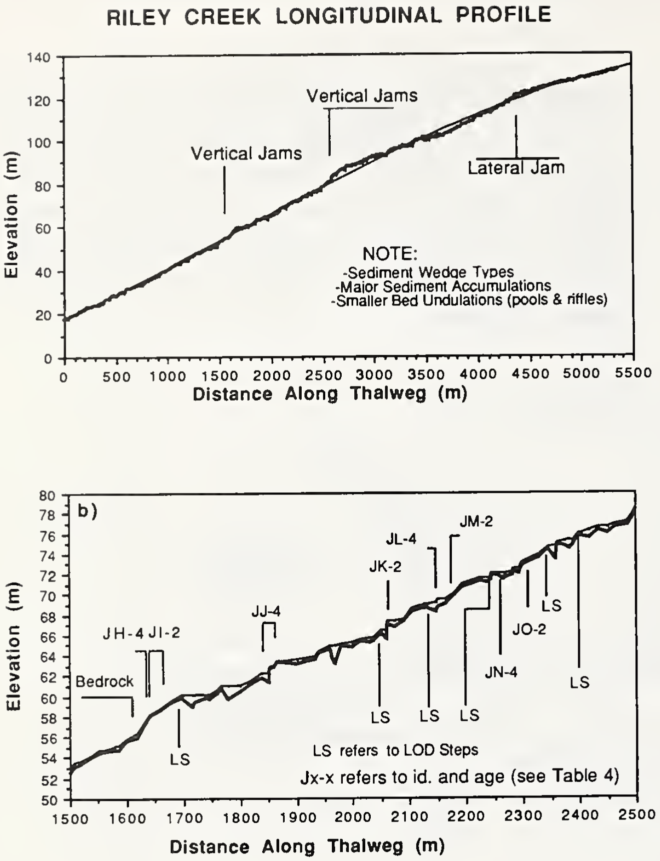


**Figure 3. A detailed longitudinal profile of Riley Creek. The symbols in Figure 3b refer to the jam identification and age (Table 4).**

and 6. The complete list of jam characteristics is included in Table 4. Age classes 2 and 3 (2-10 years and 10-30 years) are most frequent (Figure 5), but class 4 is also prevalent. The Riley Creek watershed was logged 11 years ago and several debris torrents have occurred and entered the stream since logging ceased. The adjacent watershed is similar biophysically but is unlogged. The age-frequency distribution for this creek is strongly right skewed indicating that most of the jams are relatively old (>80% of all jams fall into classes 4 and 5). More work is required to evaluate the land-use issue; this is one of the objectives of the overall project.

The debris jam's longevity and temporal influence on channel morphology is considered in Figure 6. The main factors influencing the jam's effectiveness in altering the channel relate to the degree that sediment transport is interrupted. Immediately following the establishment of a vertical jam the debris usually fills the channel both laterally and vertically and the material is usually very solid (see Table 3 for details regarding the characteristics considered in Figure 6). As time passes the height of the jam appears to remain unaltered in most cases. However, the lateral span and integrity are both reduced relatively quickly (Figure 6a). After 10 to 30 years since the jam formed its integrity is reduced to relatively low levels.

As the jam span and integrity are reduced there is a corresponding increase in sediment transport and material originally stored upstream of the jam is progressively removed and transfered downstream (Figure 6b). Therefore, as time passes, the jam becomes a less effective sediment trap and much of the sediment wedge

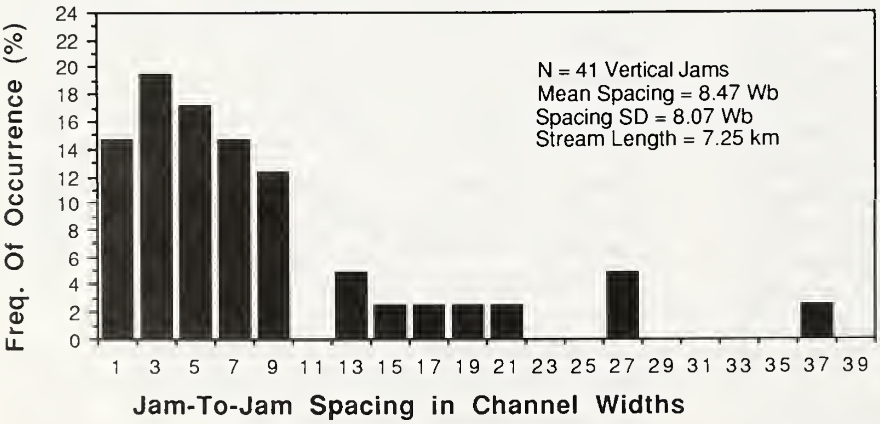


**Figure 4. Spacing of vertical debris jams in Riley Creek.**

Table 4. Vertical jam characteristics in Riley Creek (see Table 2 for details).

| Jam | Age | Integ | Span | Height | Sed.Stor | No.Chan | Location In-Chan | Along | Shape | Length |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 3 | 3 | 3 | 2 | 2 | 1 | LB | B,R | P | 3 |
| AA | 2 | 3 | 3 | 1 | 5 | 1 | RB | T? | P | 10 |
| AAA | 5 | 4 | 2 | 1 | 4 | 3 | LB | T,W | D | 20 |
| B | 2 | 3 | 2 | 1 | 2 | 1 | LB | T | P | 15 |
| BB | 2 | 1 | 1 | 1 | 1 | 3 | LB-RB | ? | D | |
| BBB | 2 | 3 | 2 | 2 | 2 | 2 | LB | DEB | P | 4 |
| C | 4 | 4 | 3 | 1 | 3 | 1 | RB | T | D | |
| CC | 2 | 4 | 2 | 2 | 2 | 3 | M | W | D | 5 |
| CCC | 4 | 4 | 2 | 2 | 3 | 3 | LB-RB | DEB | P | 3 |
| D | 3 | 4 | 5 | 2 | 2 | 1 | RB | ? | II | |
| DD | 4 | 4 | 4 | 1 | 4 | 1 | LB,RB | DEB | AU(OPEN) | 4 |
| DDD | 2 | 4 | 2 | 2 | 4 | 2 | LB | W | P | 4 |
| E | 3 | 4 | 5 | 1 | 5 | 1 | LB | B | D | |
| EE | 2 | 4 | 3 | 2 | 4 | 2 | M | DEB | P | 5 |
| EEE | 2 | 5 | 2 | 2 | 3 | 2 | LB-RB | ISL | P | 4 |
| F | 3 | 4 | 4 | 1 | 3 | 1 | LB | B | P | |
| FF | 4 | 4 | 2 | 2 | 4 | 1 | LB | W | D | 4 |
| FFF | 5 | 4 | 4 | 1 | 4 | 3 | LB-RB | W | P | 7 |
| G | 3 | 4 | 3 | 1 | 4 | 1 | LB | R | P | |
| GG | 3 | 2 | 1 | 1 | 1 | 1 | LB-RB | W,R | P | 2 |
| GGG | 4 | 1 | 2 | 1 | 2 | 1 | LB | W? | D | 15 |
| H | 4 | 3 | 3 | 1 | 4 | 2 | M | R,T | D | |
| HH | 3 | 3 | 2 | 3 | 4 | 1 | LB | W | P | 3 |
| HHH | 5 | 4 | 3 | 1 | 4 | 2 | LB,RB | T,W | AU(OPEN) | 10 |
| I | 2 | 3 | 1 | 1 | 2 | 2 | LB-RB | T,JAM | P | 10 |
| II | 3 | 3 | 2 | 3 | 3 | 1 | RB | W | P | 4 |
| J | 4 | 3 | 2 | 1 | 2 | 2 | RB | R,T | P | 5 |
| JJ | 3 | 3 | 2 | 2 | 2 | 2 | M | DEB | P | 6 |
| K | 2 | 2 | 2 | 1 | 2 | 2 | RB | W | P | 7 |
| KK | 3 | 4 | 1 | 2 | 5 | 1 | M | DEB | P | 4 |
| L | 4 | 3 | 3 | 2 | 4 | 2 | RB | W | P | 10 |
| M | 2 | 3 | 2 | 1 | 2 | 2 | RB | W | P | 20 |
| N | 4 | 3 | 5 | 1 | 5 | 1 | LB | B | D | 10 |
| O | 2 | 4 | 2 | 2 | 2 | 2 | RB | W | P | 5 |
| P | 3 | 1 | 1 | 1 | 1 | 2 | RB-LB | W,CONF | P | 20 |
| Q | 4 | 4 | 3 | 2 | 5 | 3 | M | STUMP | P | 5 |
| R | 3 | 3 | 1 | 4 | 1 | 1 | RB-LB | T | AD | 3 |
| S | 4 | 3 | 1 | 5 | 1 | 2 | LB-RB | T | P | 25 |
| T | 3 | 4 | 5 | 2 | 4 | 1 | RB | B | D(II) | 4 |
| U | 2 | 2 | 1 | 1 | 1 | 2 | LB-RB | R,B | AD | 5 |
| V | 4 | 3 | 1 | 1 | 2 | 1 | RB-LB | T | D | 3 |
| W | 1 | 1 | 1 | 1 | 1 | 2 | LB-RB | T,B | P | 7 |
| X | 1 | 1 | 1 | 1 | 1 | 1 | RB-LB | T,B | D | 5 |
| Y | 3 | 3 | 5 | 1 | 4 | 1 | LB | R | P | 3 |
| Z | 2 | 1 | 1 | 1 | 1 | 3 | RB-LB | T,R | P | 20 |

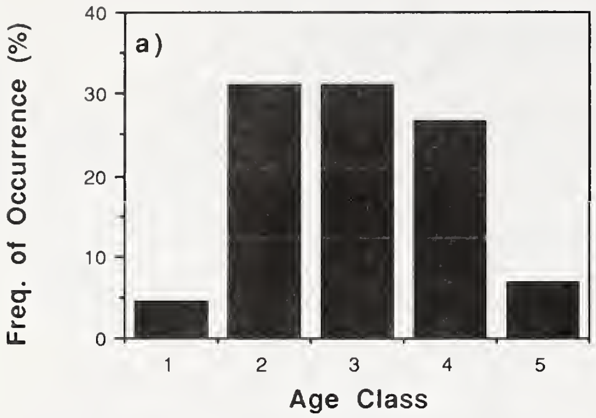


**Figure 5. Frequency of vertical debris jams by age class.**

is evacuated. Portions of the wedge become stable and are vegetated and remain intact. The number of channels associated with debris jams show a different pattern over time (Figure 6b). In the early stages there are commonly several channels (braided) cut into the sediment wedge surface. Over time, and as more of the sediment is released downstream, there ia a gradual downcutting of the upstream wedge and often a single channel carries most of the streamflow over time periods of between 10 and 50 years. However, as the jam breaks into distinct sections, for instance forming a mid channel island (eg. in Table 4), the overall channel is divided into several smaller channels. This process appears responsible for many of the side channels evident in these coastal stream systems.

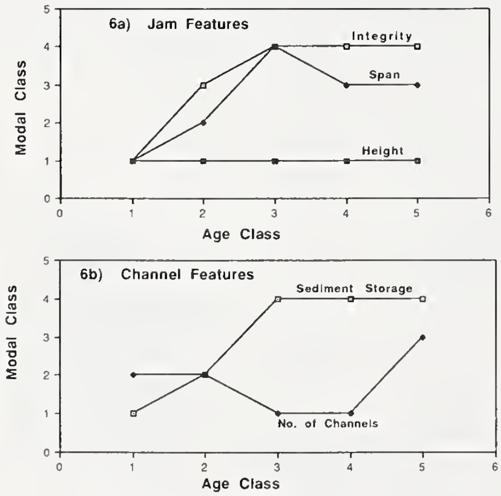


**Figure 6. Debris jam and channel characteristics.**

Several other channel changes associated with debris jam longevity can be seen in Riley Creek. These include differences in LOD characteristics, channel width and surface sediment texture (Figures 7 and 8). Debris jam locations and ages are shown in these longitudinal profiles and the graphs are arranged to enable comparison of specific features associated with the various age classes.

In all cases there is substantial channel aggradation upstream of the young (class 1) jams. An example is seen near the 3400m distance in Figure 8a (JW-1 and JX-1). In this case the bank top and bar surface graphs merge indicating that the channel bed is at the same elevation as the bank top. That is, the channel is completely filled with sediment. Degradation of the channel bed is also evident downstream of young jams (eg. 3350m-3400m , Figure 8a). As the jams age, more sediment is excavated and the bed upstream of the jam downcuts and sediment is transfered downstream. For example, in Figure 7a there is relatively little channel filling between 300m and 1000m although there are four large jams along this zone (jam size is indicated in Figure 7b). At JB-2 (150m-210m) the channel again shows evidence of sediment filling.

Debris jam size also appears to be influenced by time. The newer jams are larger than the older jams (Figures 7a & b and 8a & b). Also, the debris making up the newer jams are oriented predominately across the channel and the older jams are composed of debris oriented more parallel to the streamflow direction. This shift in orientation alters the function of the debris; the parallel material is less effective in trapping sediment and promoting bed and bank scour.

Changes in channel width and sediment texture can also be related to debris jam age (Figures 7d & e and 8d & e). In most cases where the channel walls are not confined by bedrock there is an increase in channel width associated with the newer jams. Coinciding with the new jam and wider channel is a reduction in surface sediment sizes. In most instances the sediment is finer immediately upstream of the jam and considerably coarser downstream. These width and sediment sorting characteristics are not as evident in the older jams.

In summary, this case study indicates that debris jams are a fundamental feature of these small coastal streams. It appears evident that vertical jams are prevalent along the entire stream system and their function changes over time. A series of generalized models showing the temporal evolution of these streams is presented in Figure 9. These models are based upon the information presented in this paper and supplemented by project field work.

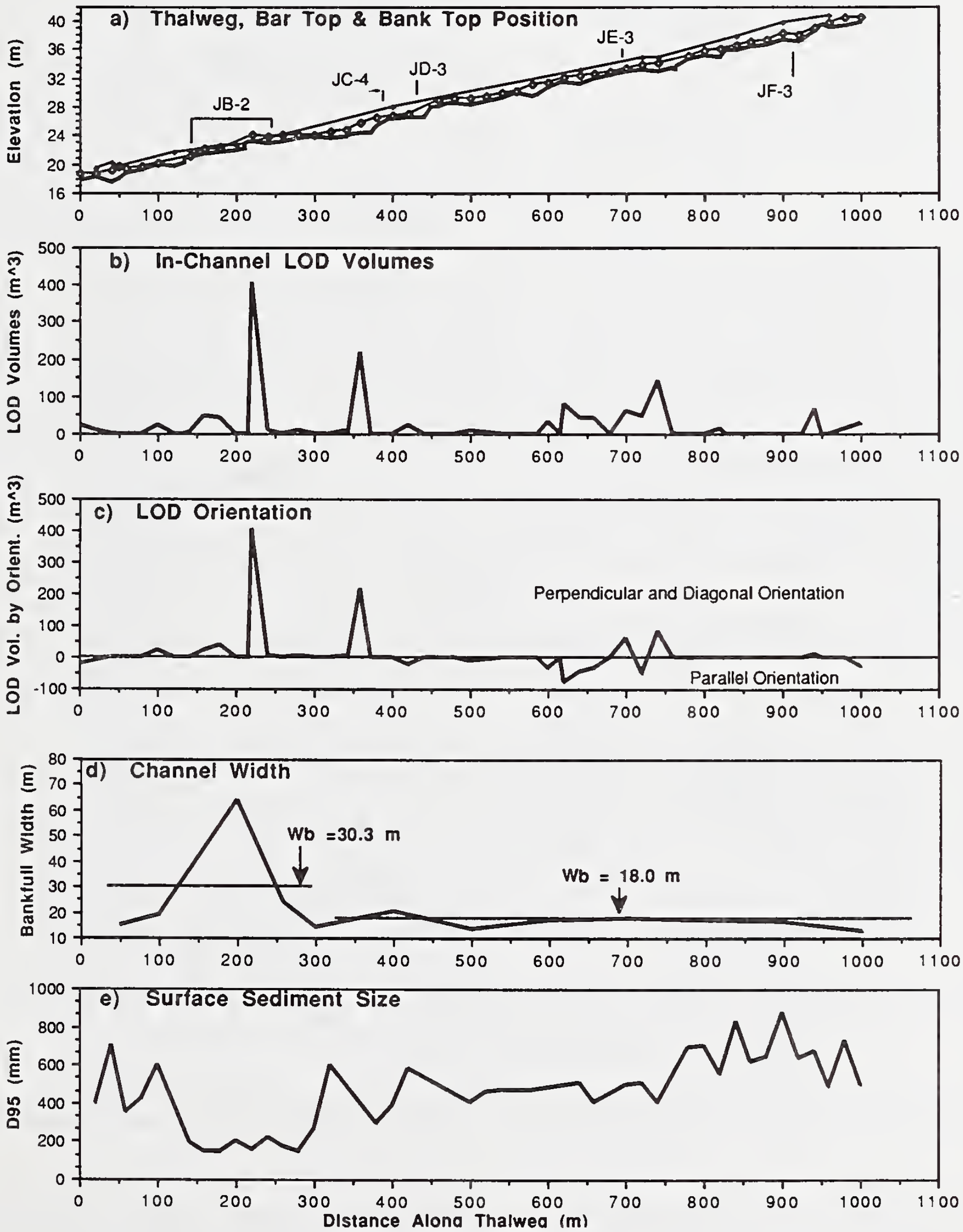


**Figure 7. Channel changes associated with vertical jam longevity, 0 to 1100 m along the thalweg.**

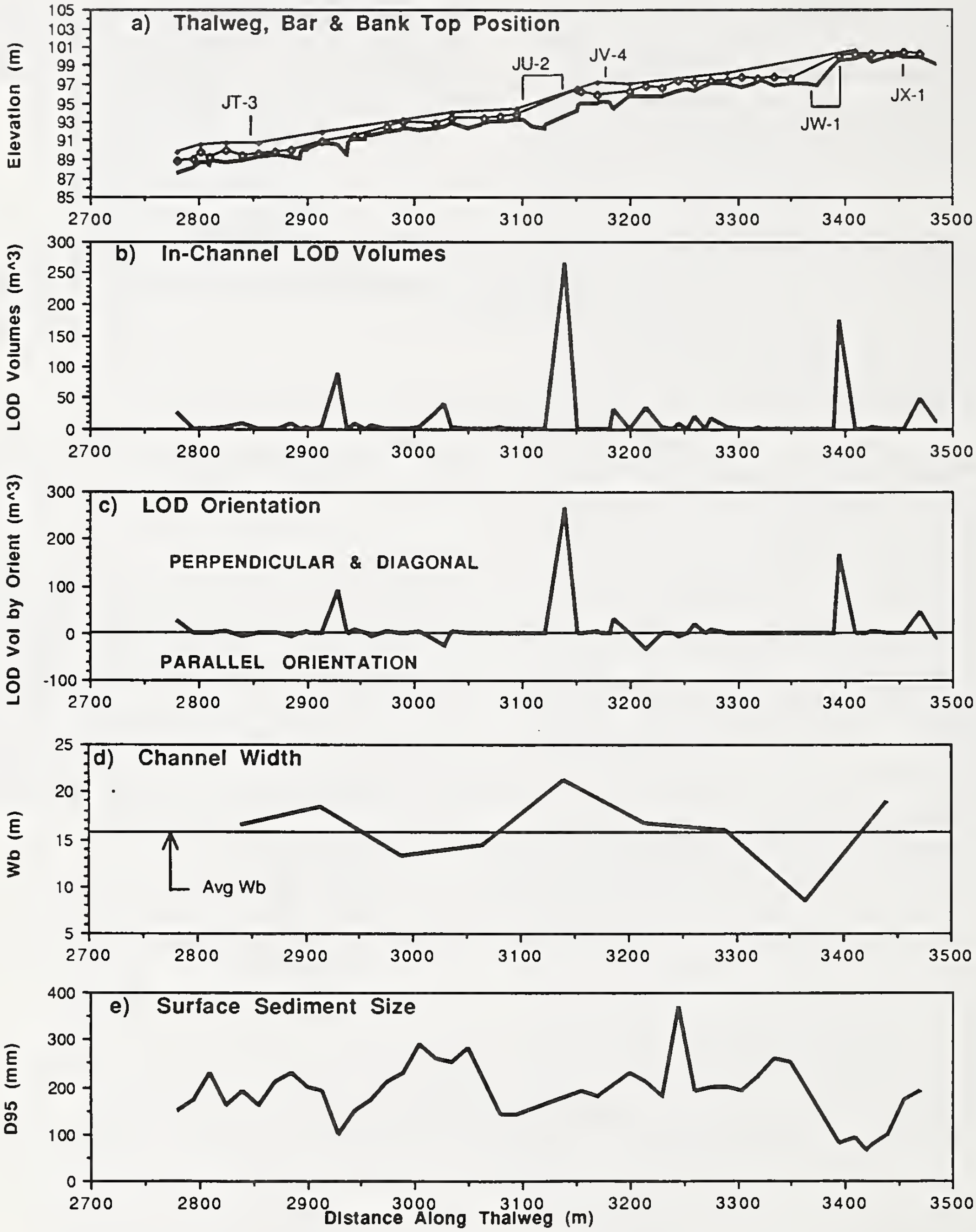


**Figure 8. Channel changes associated with vertical jam longevity, 2700 to 3500 m along the thalweg.**

Typical changes in channel morphology over time and space are noted in Figure 9. The sequences are self-explanatory. In general, models show a channel that is very morphologically complex before being influenced by a debris torrent, but the channel is greatly simplified immediately following the input of debris and sediment from a mass wasting event. Gradually the channel features return to their pre-disturbance condition. The model sequences show a channel returning to this condition in time periods on the order of three decades. Again, the models are intended as a summary of our initial work and they will undoubtedly be changed as the study progresses.

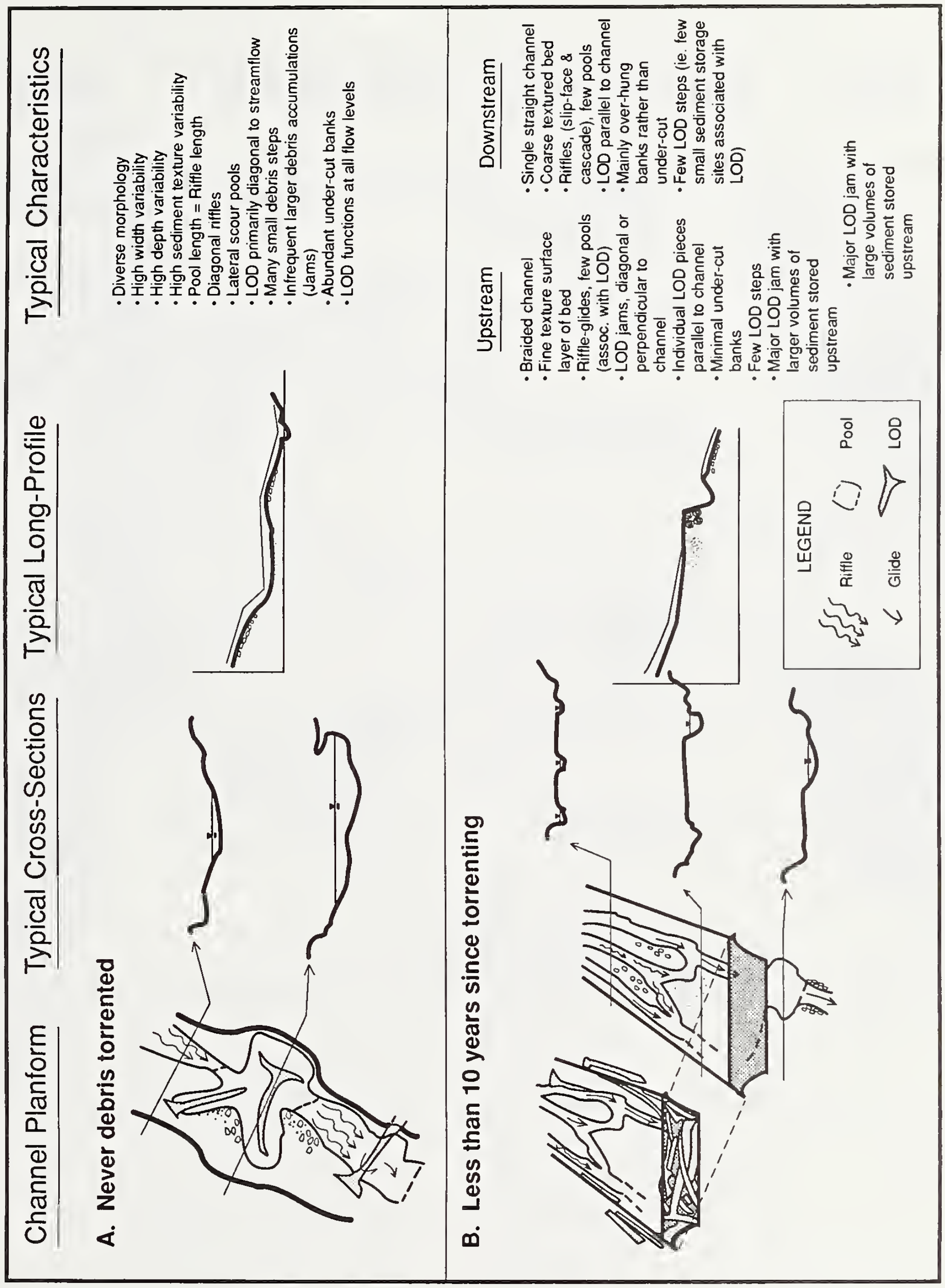


**Figure 9. Channel morphology associated with vertical sediment wedges.**

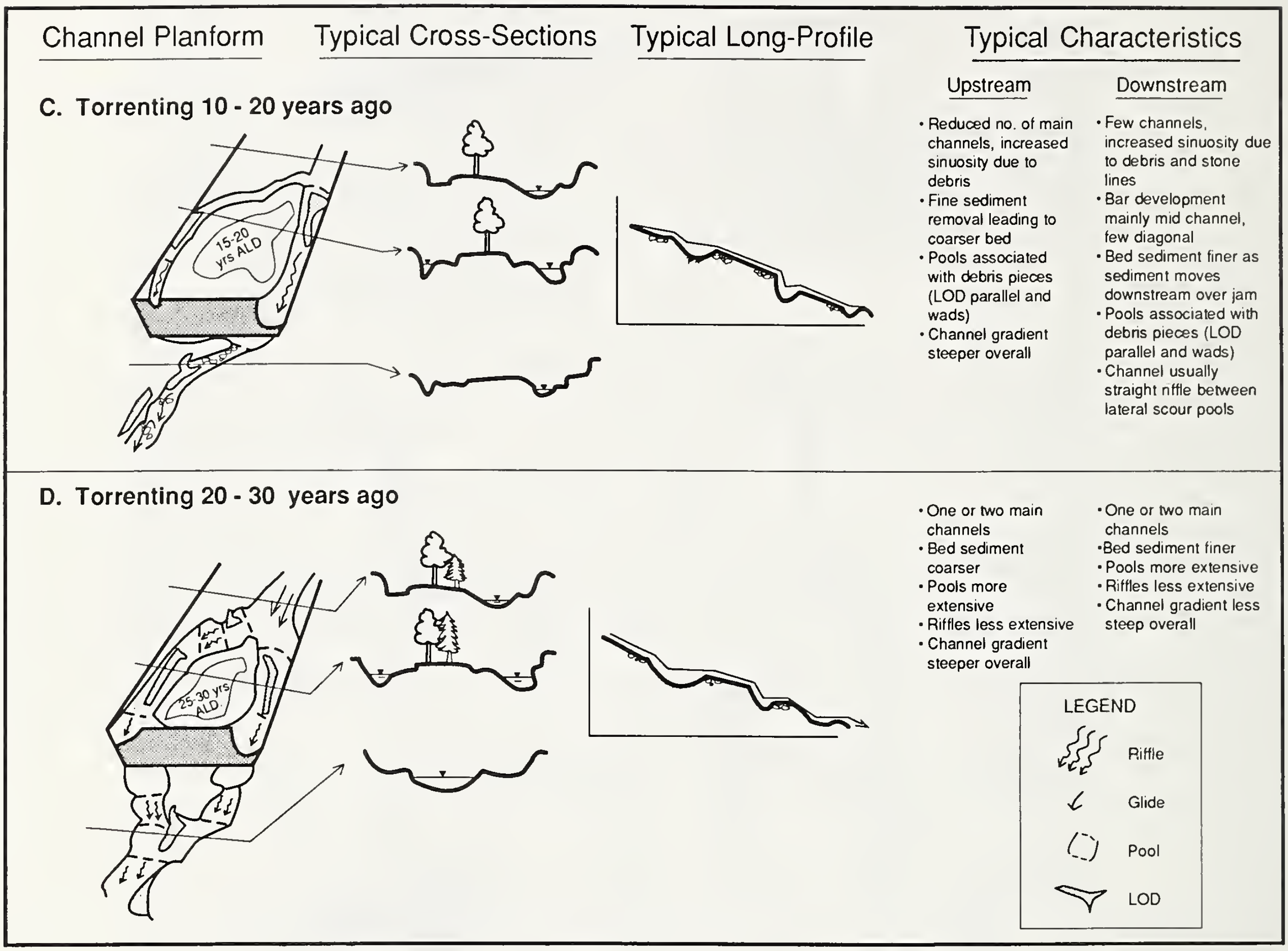


**Figure 9 (Continued).**

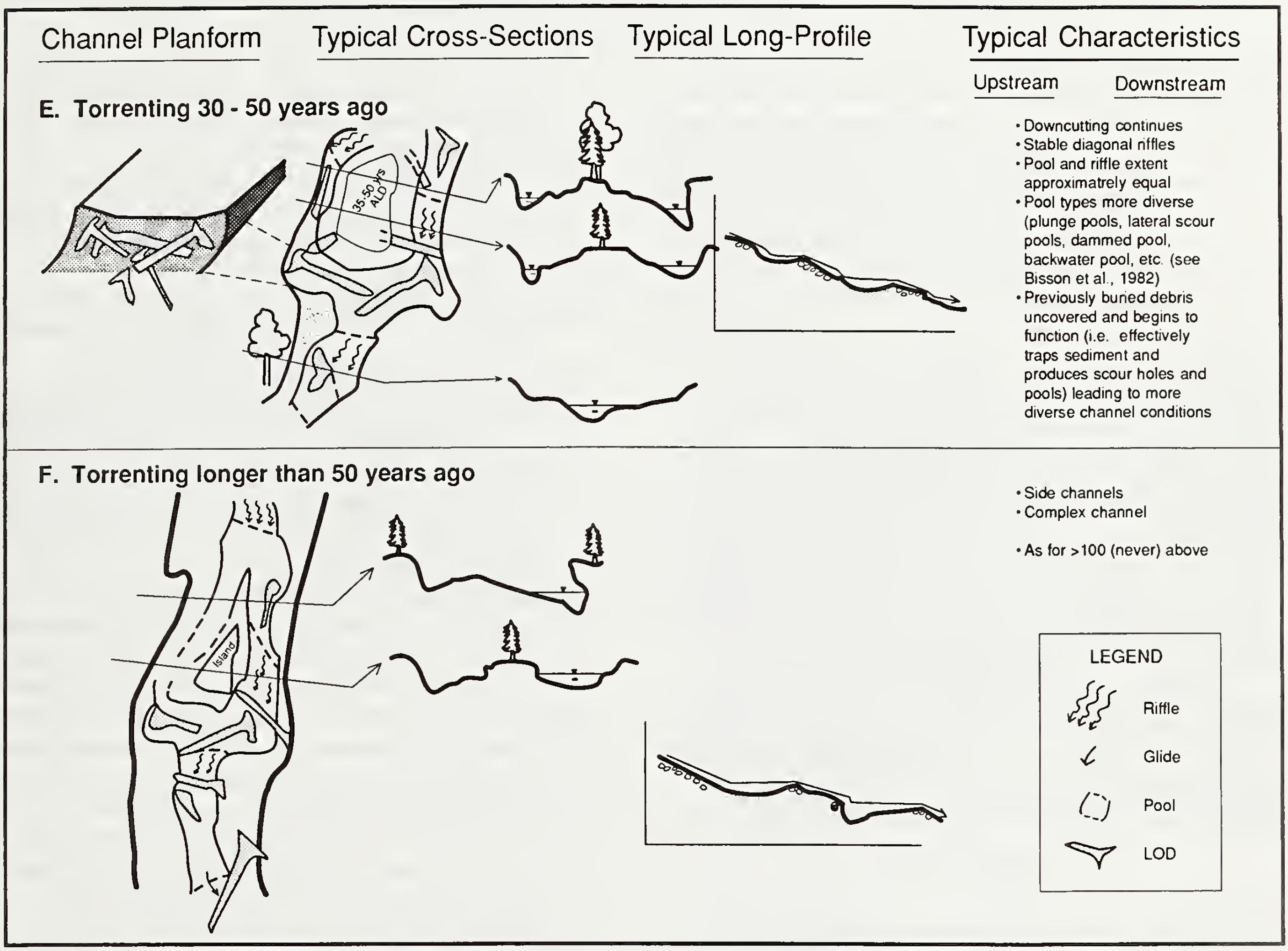


Figure 9 (Continued).

## Conclusions

A case study has been presented to provide initial results from the first year of a four year project. The study is designed to evaluate the temporal and spatial response of stream channels to mass wasting impacts in the Queen Charlotte Islands.

Preliminary results from a single small coastal stream indicate that a fundamental consequence of debris torrent inputs is the establishment of sediment wedges associated with debris jams. The sediment wedges are of two basic types, vertical and lateral, and each has a particular general form and influence on the channel. The location, size and function of each type of jam controls morphology and their distribution along the water course influences the spatial adjustment of the channel. Specific sedimentological, morphological and hydraulic changes occur upstream and downstream of the jams. The integrity and longevity of the debris jams control the temporal response of the channel. Initial results show that severe morphological alterations persist during the first decade following debris torrenting, but the channel begins to develop more normal characteristics during the second and third decades. The morphological nature of stream channels after 30 years since disturbance begin to resemble undisturbed channels. The temporal and spatial response of a stream channel to mass wasting inputs has important implications to both the fishery and forestry industries.

A series of generalized models showing the temporal evolution of these streams has been presented. Study will continue in a wider range of stream sizes and in different geographic regions so that refinements or modifications can be made to the generalized models.

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# A Sediment Transfer Hazard Classification System: Linking Erosion to Fish Habitat

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***Abstract.*** A problem in watershed management is linking upslope erosion associated with forestry practices to downstream sedimentation of fish habitats. To overcome this problem, a sediment transfer hazard classification system was developed and applied to a northwestern British Columbia watershed. The system is based on geomorphic factors that influence sediment production, transport, and deposition. Data to describe these factors are obtained from air photographs, topographic maps, fish habitat inventories and interpretive terrain maps. The final product of the system is a sediment transfer hazard map that indicates where in a watershed sediment production and movement is a potential problem. This is an important tool for watershed and integrated resource managers because not all unstable or erodable sites pose a sedimentation hazard to fish. Knowing the hazards, managers can decide in an informed way where to restrict forest harvesting or focus limited dollars on special road construction and harvesting techniques. This paper describes the Sediment Transfer Hazard Classification System.

Many watersheds along the Pacific Northwest coast have high forestry and fisheries values. For this reason, integrated resource management is a common goal of resource managers in both Canada and the United States. This goal has been supported by several major research programs (e.g., Salo and Cundy, 1987; Scrivener, 1987; Poulin, 1984). These programs have expanded our understanding of physical and biological processes and have led to improved watershed management. However, one persistent shortcoming has been the failure to provide an *operational* planning tool that links individual processes so that downstream impacts, due to sediment introduced at some point upstream, can be predicted. Conceptual models have been presented in the literature (e.g., Swanson *et al.*, 1982; Church, 1983; Megahan, 1985), but these fall short of operational needs.

As a result, inputs to operational forest land use planning include discrete components, with little or no integration. For example, routine interpretive terrain maps identify the potential for upland erosion, but there is no operational methodology presently available that links these areas to potential sedimentation hazards in downstream fish habitats. While resource managers rely on their own individual approaches, until a consistant hazard assessment is established, true integrated resource management will remain a concept rather than a reality.

To address this situation, a method that links upslope erosion to fish habitat was developed and applied to a northwestern British Columbia watershed. The objective of this paper is to describe the method, the "Sediment Transfer Hazard Classification System".

The system is based on key geomorphic factors that influence sediment production, transport and deposition. The assessment of downstream hazards is accomplished by viewing the overall watershed as a network of linked tributaries and mainstem channel segments that transfer both water and sediment to the watershed outlet. The system evaluates the sediment transfer characteristics *within* each tributary and mainstem channel segment and then estimates potential for transfer *between* different areas of the watershed. Therefore, the sequential arrangement of tributary and mainstem stream channels determines whether an upstream sediment source is *connected* to sensitive environments downstream.

The final product of the system is a sediment transfer hazard map that indicates where sediment production and movement is a potential problem. This is a useful tool because it indicates where special operational measures to control sediment production are most critical.

The system is designed to be used as an operational planning tool. The terrain and stream channel data requirements are obtained from air photographs, topographic maps and terrain maps. Field work requirements are minimal.

## Description of the System

The movement of sediment from a source to a downstream fish habitat involves many hillslope and stream processes. A useful way to illustrate the movement is through a sediment transfer model (Figure 1). Hillslope materials are moved downslope by various processes; for example, rockfalls, debris slides and soil

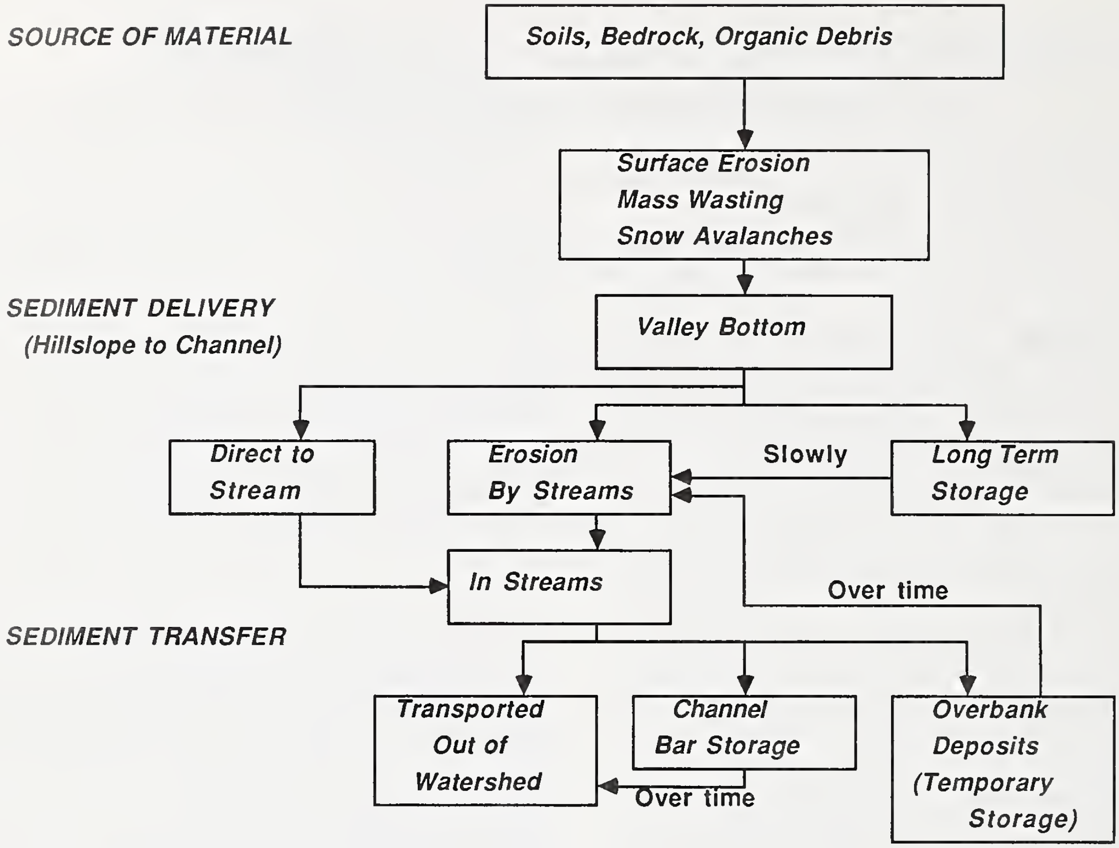


**Figure 1. A conceptual model of sediment transfer.**

creep transfer sediment from the hillslope to the valley bottom. Eventually this material enters a stream channel, often as a result of streambank erosion, and is moved downstream by fluvial sediment transport mechanisms. The transfer of sediment is rarely continuous over time or space, so the downslope/downstream movement through the watershed is sporadic and sediment is stored in specific zones for various time periods. The efficiency of sediment transfer from a source can be anticipated based on the surrounding terrain and fluvial characteristics. The Sediment Transfer Hazard Classification System links these features to provide an operational planning tool for resource managers. The approach has been generalized in Figure 2 to show the importance of channel and sub-basin arrangement, with respect to the downstream sensitive environments. Figure 2 also illustrates the kinds of questions and issues considered and the steps followed. A simplified schematic showing the general features considered to evaluate sediment delivery to the stream channel and sediment throughput to the sensitive environment downstream is given in Figure 3.

The system involves five main steps (Figure 4): defining the fish habitat; describing the geomorphic features of the watershed; determining sediment delivery potentials; evaluating channel sediment throughput by reach and tributary; and integrating this information to define sediment transfer hazards. This information is presented on a large scale map.

*Delineation of Fish Habitat*

The initial step is to determine the location of important fish habitat such as spawning or rearing areas (Figure 4). This defines the stream reaches that are critical from a sediment deposition and channel morphology standpoint. These areas are identified on the largest scale base map available. This information is generally available from fisheries agencies, but if not, field work may be necessary.

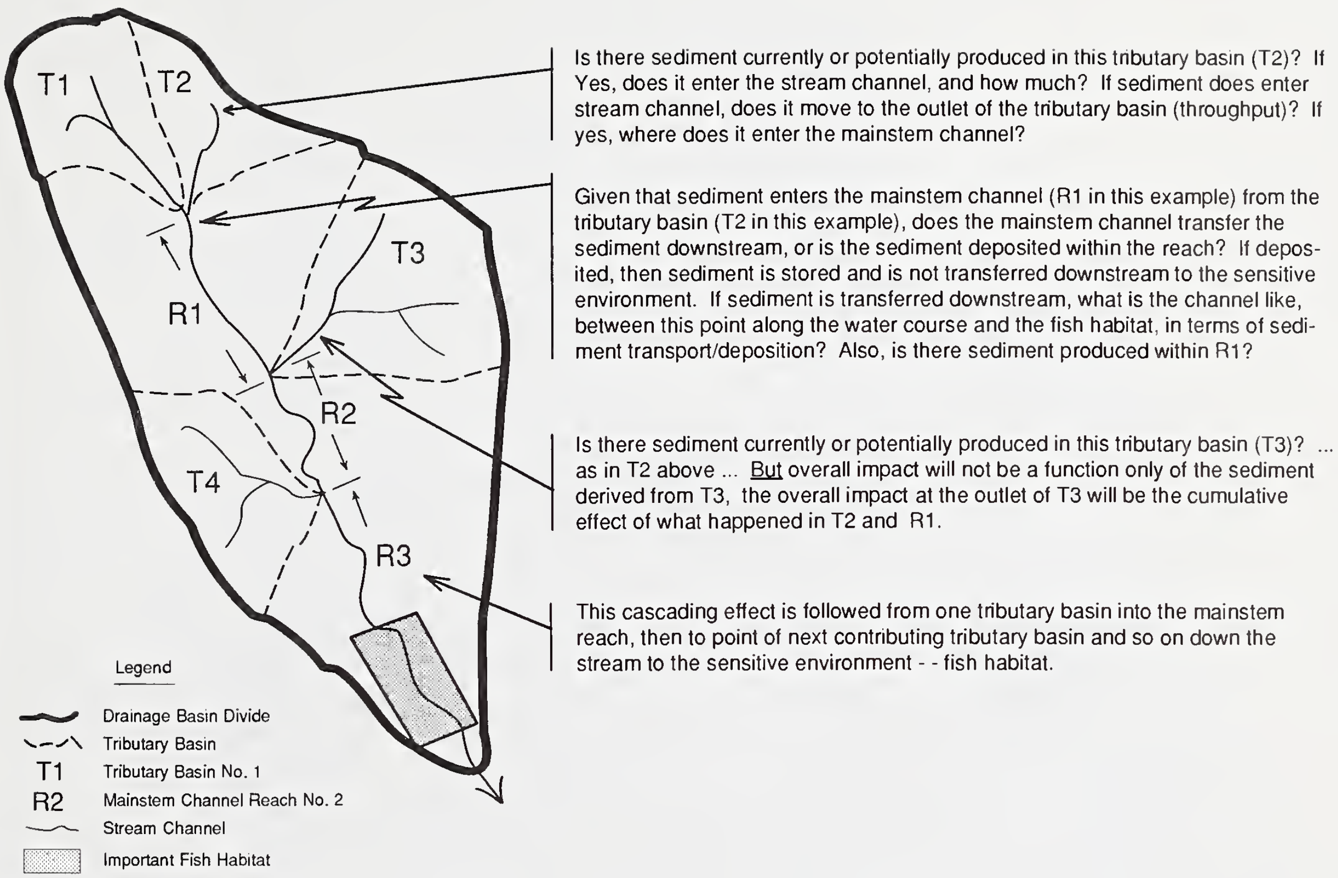


**Figure 2. A schematic diagram showing the general approach to the sediment transfer hazard classification system.**

*Geomorphic Description*

Details from the geomorphic description are used in determining sediment production, delivery and throughput potential. The channel network is divided into tributary and mainstem channels (Figure 4) each with their associated contributing watersheds (subbasins). Homogeneous reaches of the mainstem stream channel are delineated on a base map and key morphological features are identified from airphotos and topographic maps (Table 1). The tributary watersheds are delineated and specific features are measured from the largest scale topographic maps and air photographs available (Table 2). Due to canopy closure and the smaller size of these channels, it is generally not possible to identify the same types of channel features on the tributaries as on the mainstem reaches.

*Hillslope Sediment Delivery Potential*

There are two components to the assessment of sediment delivery potential: identifying the nature of sediment sources; and evaluating these sources relative to potential sediment delivery to stream channels.

*Sediment Sources*. There are two basic types of sediment source: existing and potential. In most forest planning applications, existing sources are natural or background sources, but in some cases there may be previous logging or other human disturbance that is producing sediment. Potential sources are those that can produce sediment given certain land use practices (e.g. road construction).

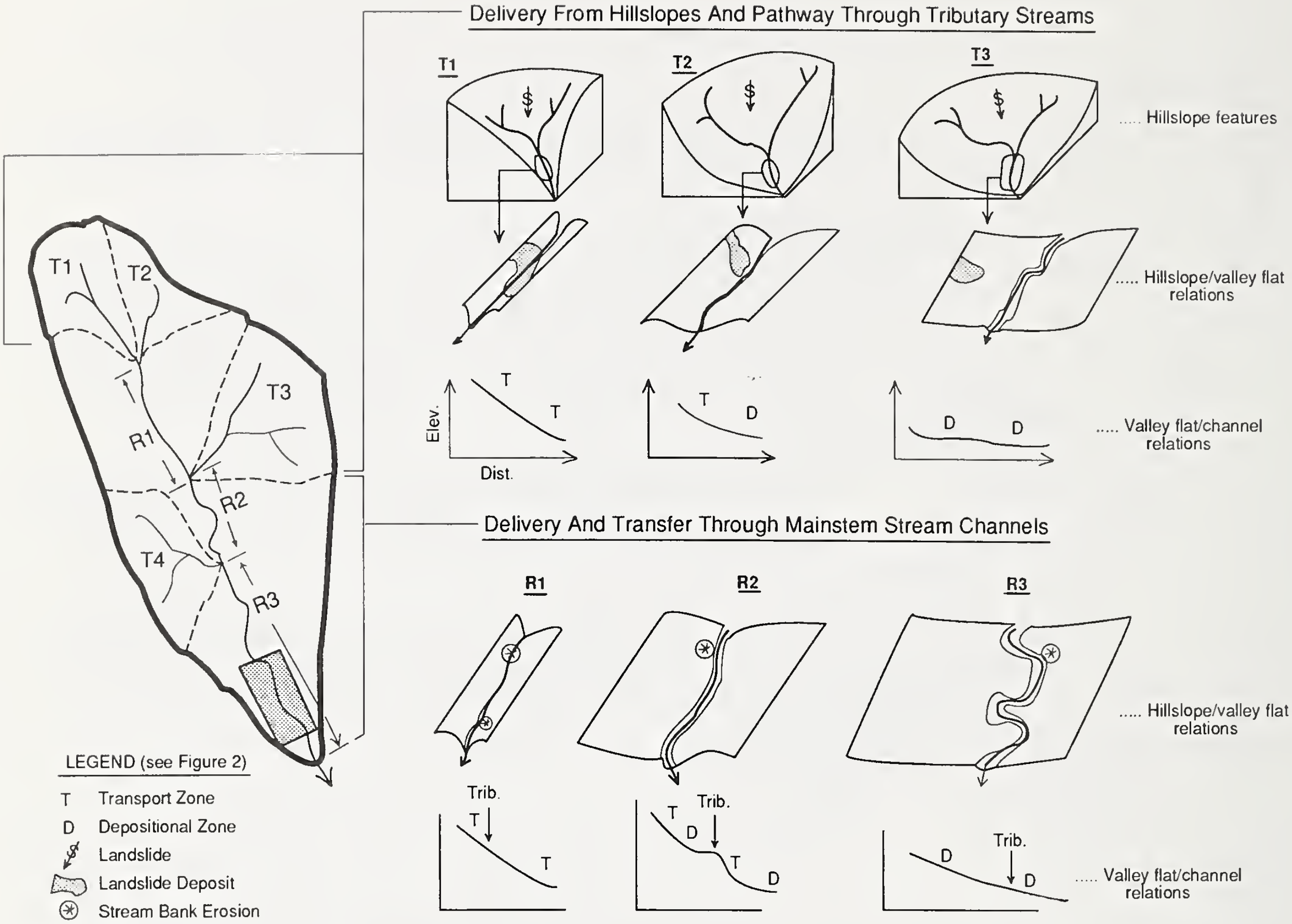


**Figure 3. A schematic diagram illustrating the general feature considered to evaluate sediment delivery to the stream channel and sediment throughput to the fish habitat.**

**Table 1. Descriptive features of mainstem channel reaches.**

| | |
|---|---|
| Total Basin Area | Reach Gradient (profile) |
| Reach Length | Reach Sinuosity |
| Channel Pattern | Predominant Bar Type |
| Predominant Bed Material | Predominant Bank Material |
| Predominant Bank Vegetation | Lateral Stability |
| Hillslope-Valley Flat Relations | Reach Type |
| Valley Flat-Channel Relations | |

**Table 2. Tributary basin characteristics.**

| | |
|---|---|
| Total Sub-Basin Area | Channel Gradient (profile) |
| Channel Length | Length of Channel <1% Gradient |
| Valley Flat Extent | |
| Number of Lakes | Area of Lakes |
| Number of Swamps | Area of Swamps |

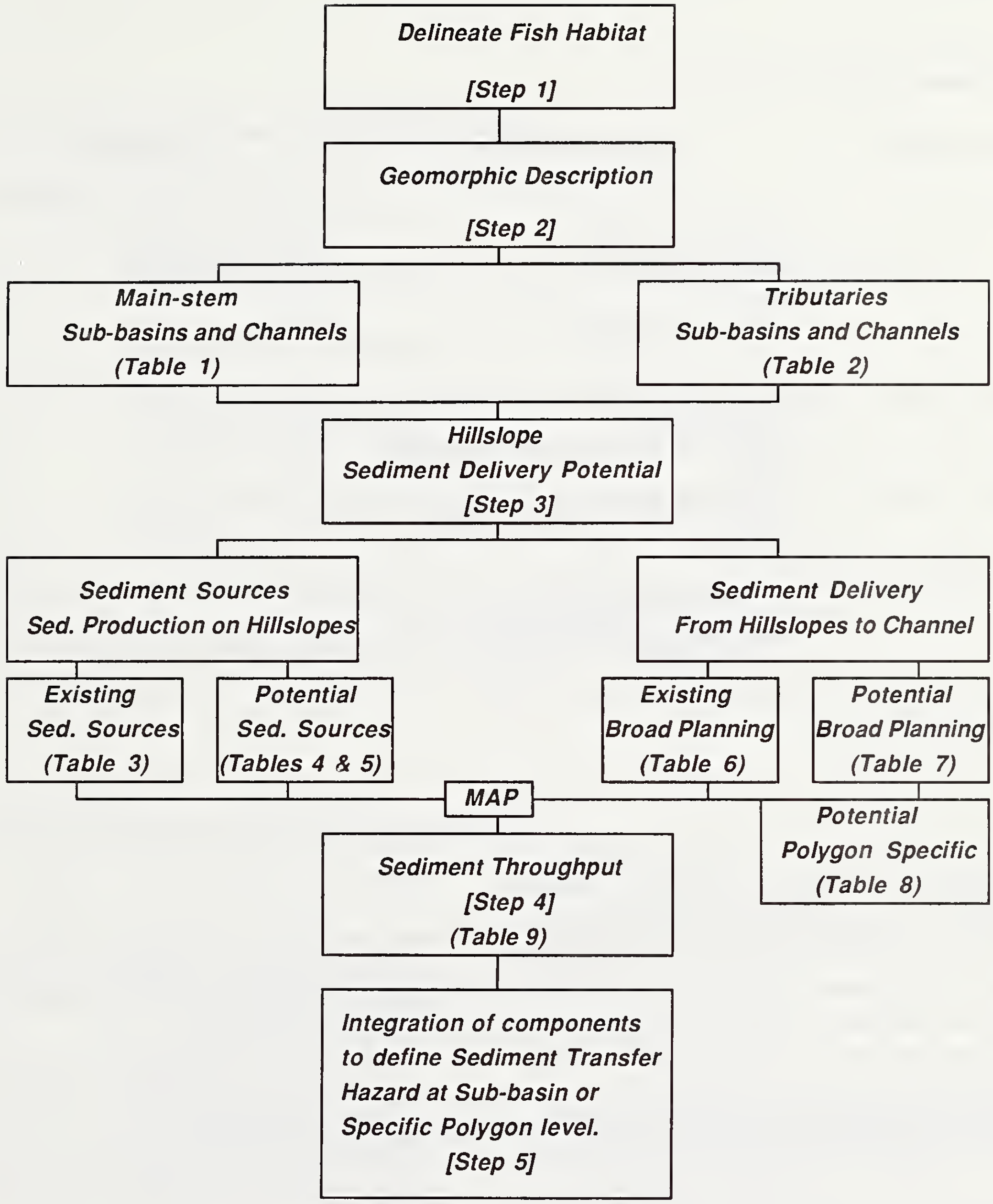


**Figure 4. A flow diagram outlining the steps followed to classify the Sediment Transfer Hazard Zones for resource development planning. (Tables and Steps are discussed in the text).**

**Table 3. Existing Sediment Sources**

| General Type | Sediment Source | Map Symbol[1] |
|---|---|---|
| Areal | active colluvial slope | C-R, C-Rs, C-Rd |
| | active till slopes | M-R, M-Rs, M-Rd |
| | glaciers | I |
| | active bedrock cliffs | R-Rf |
| Linear | snow avalanches | A |
| | active gullying | V |
| | steep channels with high sediment loads | -> |
| | multiple steep, low order stream channels | E |
| Point | stream bank erosion | ● |
| | small slides and debris flows | x |
| | anthropogenic | a |

[1]Howes and Ryder, 1984

Sediment and organic debris can be produced from numerous existing sources (e.g., streambank erosion, mass wasting, and snow avalanches). These sources are identified on terrain or landform maps (Ryder and Howes, 1984). The maps should cover an entire watershed so all existing sources of sediment production can be determined. Existing sediment sources are grouped into three general types: areal, point and linear (Table 3).

Potential erosion hazards for forestry are identified on interpretive maps of erosion potential; a common planning tool on the coast of British Columbia. The interpretive maps identify homogeneous polygons and generally have 5 classes for surface erosion potential and 5 classes for potential mass wasting or slope instability (Tables 4 and 5). Polygons are determined qualitatively based on soil texture, landform, slope angle and shape, soil moisture, natural erosion processes, and past incidence of logging related erosion in similar terrain (J. Schwab pers. com., 1988). These maps are usually produced at a scale of 1:20,000.

*Sediment Delivery to Stream Channels*. There are two levels at which sediment delivery from hillslopes to stream channels can be determined: broad planning; and specific to a landscape feature.

The broad planning level allows watersheds to be compared at an early planning stage, and highlights where the sediment delivery is a current or potential problem. This planning level infers delivery of sediment from hillslopes to stream channels based upon the spatial occurrence and type of natural and potential sediment sources. The basic unit for assessing sediment delivery is the tributary or main channel segment watershed, and a label is attached to the downstream end of each watershed (this information is presented on an overlay map). The criteria are presented in Tables 6 and 7. The class limits are scale dependent and must be modified to reflect the range of conditions in a specific area.

**Table 4. Classes for surface erosion potential.**[1]

| Symbol | Class Definition |
|---|---|
| VL | very low potential for surface erosion: flat or very gently sloping terrain |
| L | Low potential: gentle slopes and short slopes |
| M | Moderate potential: moderately steep slopes and long slopes; some gentler but relatively moist slopes |
| H | High potential: steep slopes, and some moderately steep but relatively moist slopes |
| VH | Very high potential: very steep slopes with presently active slope proceses |

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[1]J.M. Ryder. 1987. Terrain analysis for the Hanna-Tintina area. 93p.

**Table 5. Classes for slope stability potential.**[1]

| Symbol | Class Definition |
|---|---|
| I | Flat or very gently sloping land; stable |
| II | Gentle slopes with little potential for instability |
| III | Moderately steep slopes with intermediate potential for instability, especially where ground is relatively moist and where bedrock is present at shallow depths. |
| IV | Steep slopes with high potential for instability |
| V | Slopes presently unstable at many sites and with very high potential for increased instability |

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[1]J.M. Ryder. 1987. Terrain analyses for the Hanna-Tintina area. 93p.

**Table 6. Sediment delivery within sub-basins: existing erosion.**

| Symbol | Class Definition[1] |
|---|---|
| VL | Very low levels of sediment input from the hillslopes or terrain unit. Only stream bed and stream banks contributing minimal sediment to the stream. |
| L | Low levels of sediment input from one or more of the following contributions:<br>•Areal sources; ≤10%<br>•Linear sources; drainage density ≤0.1 km/km$^2$<br>•Point sources; ≤5 per km$^2$ (historic only) |
| M | Medium levels of sediment input from one or more of the following contributions:<br>•Areal sources; 11-20%<br>•Linear sources; density 0.11-0.2 km/km$^2$<br>•Point sources; 5-10 per km$^2$ |
| H | High levels of sediment input from one or more of the following contributions:<br>•Areal sources; 21-30%<br>•Linear sources; density ).21-0.3 km/km$^2$<br>•Point sources; 11-15 per km$^2$ |
| VH | Very high levels of sediment input from one or more of the following contributions:<br>•Areal sources; >30% of area<br>•Linear sources; density 0.34 km/km$^2$<br>•Point sources; >15 per km$^2$ |

[1]The class limits are scale dependent and must be modified to reflect the range of conditions in a specific area. Values given here were used in an operational application.

The specific level of sediment delivery addresses the question - if sediment is produced at a given point in a watershed, will it reach a stream channel? (See Figure 2.) Specific delivery potential is dependent upon the nature of both the source and the landscape between the source and the stream. The specific level focuses on the polygons of the erosion potential maps, and becomes a suffix to the polygon label (Table 8). The specific level is used in the development of detailed plans for roads and cutting units.

The map presentation of sediment delivery concludes step three of the Sediment Transfer Hazard Classification System. The last step is to assess the sediment throughput of channels.

*Sediment Throughput.* The ability of a stream channel to entrain and transport sediment is a function of several factors (e.g., stream velocity, local channel gradient, nature of the bed and bank materials, channel shape and morphology, etc.). However, it is rarely feasible to collect specific data regarding these factors and it is usually impossible to rely on direct measurements when making management decisions at the operational level. For this reason it is necessary to use indirect measures of sediment transport to assess the probability that sediment introduced at one point will be moved downstream. Sediment throughput is assessed here from air photographs and topographic maps. The morphology and sediment character of each tributary and mainstem reach is documented from air photos (Tables 1 and 2). This is evaluted along with reach gradient, channel-valley flat relations and channel shape to classify throughput (Table 9). The gradient intervals in Table 9 are scale dependent and must be modified to reflect the range of conditions in a specific area.

The sediment throughput classes for the main tributaries and main stem reach segments are colour coded onto the 1:20,000 overlay map.

*Using The System.* The Sediment Transfer Hazard Classification System can be applied at two levels: the broad planning level; and the specific, cutting permit level.

**Table 7. Sediment delivery within sub-basins: potential erosion.**

| Symbol | Class Definition | |
| --- | --- | --- |
| I | Very low levels of potential surface erosion or hillslope instability. Expansive low relief terrain effectively stores sediment so that delivery to the stream channel is disconnected. Sediment delivery from terrain units is not important. | |
| II | Low levels of potential erosion. | |
| | Surface Erosion H and VH or Hillslope Instability IV & V | <10% of total area of sub-basin |
| | Low relief terrain less extensive than in Class I, less than 10% of the high erosion polygons border or intercept a stream channel. | |
| III | Medium levels of potential erosion. | |
| | Surface Erosion H and VH or Hillslope Instability IV & V | 10-20% of total area of sub-basin |
| | All polygons are separated by a medium sized valley flat or low relief terrain (VF is 3-5wb), but other terrain features (e.g., gullies, low order streams) will transfer medium amounts (10-30% of total) to the stream. | |
| IV | High levels of potential erosion. | |
| | Surface Erosion H and VH or Hillslope Instability IV & V | 21-30% of total area of sub-basin |
| | A narrow valley flat or low relief terrain (VF ≤3wb) separates the potential erosion sites from the channel but other terrain features (e.g., gullies, low order streams) will deliver much (30-70%) of all potentially eroded sediment to the channel. | |
| V | Very high levels of potential erosion. | |
| | Surface erosion H and VH or Hillslope Instability IV & V | >30% of total area of sub-basin |
| | Steep relief and no valley flat will deliver most or all (70-100%) of all potentially eroded sediment to the stream channel. | |

Table 8. **Sediment delivery from individual potential erosion polygons.**

| Symbol | Class Definition |
|---|---|
| I | Very low levels of sediment delivery. The polygon does not border or intercept any stream channel. A very broad valley flat, or low relief terrain effectively disconnects the potential sediment source and the channel. |
| II | Low levels of sediment delivery. The polygon is separated from all streams by a wide valley flat or low relief terrain (VF ≥5 wb). Only minor amounts (≤10%) of the potential sediment eroded will reach the channel. |
| III | Medium levels of sediment delivery. The polygon is separated from streams by a medium sized valley flat or low relief terrain (VF 3-5 wb), but other terrain features (e.g., gullies, low order streams, etc.) may transfer low, but measureable amounts of sediment to the channel (10-30%) of potentially eroded sediment. |
| IV | High levels of sediment delivery. The polygon is separated from the stream channel by a narrow valley flat of low relief terrain (VF ≤3 wb) but other terrain features (e.g., gullies, low order stream channels) will deliver much (30-70%) of the potentially eroded sediment to the channel. |
| V | Very high levels of sediment delivery. The polygon directly borders a stream channel. the terrain is steep and all sediment produced will be delivered to the channel. There is no valley flat. Sediment is directly connected to the channel. All potential sediment (70-100%) will enter the channel. |

At the broad planning level there are two key components. The first is the sediment delivery overlay map that characterizes existing and potential sediment movement to channels at the sub-basin level (Tables 6 and 7). The second component is the Sediment Throughput overlay map of the channel network according to Table 9. These two components are linked in a matrix (Figure 5) to determine the sediment transfer hazard from a specific sub-basin. For example, if a sub-basin has a high level of existing sediment input (H) and a very low level of sediment throughput (Class 1), the Sediment Transfer Hazard is low. Thus the hazard reflects not only the amount of sediment input but also the ability of the channnel to transport the sediment. The only exceptions are channel reaches with high fish values (Class 1a and 2a). Due to the depositional nature of these channels and their high fish values, they require special attention (e.g., sediment that is not transfered *is* a problem).

At the broad planning level the matrix identifies the sediment transfer hazard for a sub-basin. The next step is to use the Sediment Throughput map to determine how effective the channel network is with regards to sediment delivery between the sub-basin and the fisheries sensitive areas (Class 1a reaches). Any channel that has a low sediment throughput (i.e., class 1 or 2) will act as a sediment sink. Thus the probability of sediment transfer from any sub-basins above a Class 1 channel is low. As the sediment throughput class increases, the probability of delivery increases. Thus the sequencing of Sediment Throughput Classes is critical in the overall assessment of impacts to the fisheries sensitive area.

At the specific cutting permit level there are also two key components that are used to assess the potential for sediment leaving a specific site and impacting on a fisheries sensitive area. The first component is the sediment delivery suffix (Table 8) on the potential erosion map. This label indicates the level of sediment delivery risk associated with the polygon. The second component is the Sediment Throughput overlay map of the channel network according to Table 9. As with the broad planning level, the matrix (Figure 5) is used to

**Table 9. Sediment throughput classes.**

| Class | Description | Interpretation | Color Code |
|---|---|---|---|
| 1& 1a | Very low level of sediment throughput. Although headwaters may be steep, the basin has mainly low gradient channels (≤0.1%) with very wide valley flat and lakes/swamps. These channels store sediment. | There are two types of Class 1: 1. A depositional stream channel with no fish values | Green |
| | | **1a**. A depositional stream channel with high fish values. A high hazard channel. | Green with X's |
| 2& 2a | Low level of sediment throughput. Lakes are present but are less effective sediment sinks due to location and size. Swamps are extensive, channels are low gradient (0.1-0.9%) and the valley flat is wide (>>5 wetted bank widths (Wb)). | There are two types of Class 2: **2**. No problem if cautious due to low sediment transfer capability. | Blue |
| | | **2a**. A depositional stream channel with high fish values. A moderately high hazard channel. | Blue with X's |
| 3 | Moderate level of sediment throughput. Few large sediment sinks (lakes and swamps are small or ineffective). Steeper channel gradients (1.0-2.0%) with channel bars. Valley flat 3-5Wb. | Concern. Sediment transfer requires caution. | Yellow |
| 4 | High level of sediment throughput. Mainly steeper gradient channels (2.0-5.0%) with minor localized low gradient sections. Less extensive channel bars and valley flat is confined (1-3Wb). | High level of concern requiring detailed assessments and close supervision. | Red |
| 5 | Very high level of sediment throughput. Steep channels (≥5%) with no channel bars or valley flat. | Avoid - these channels transport all sediments. | Black |

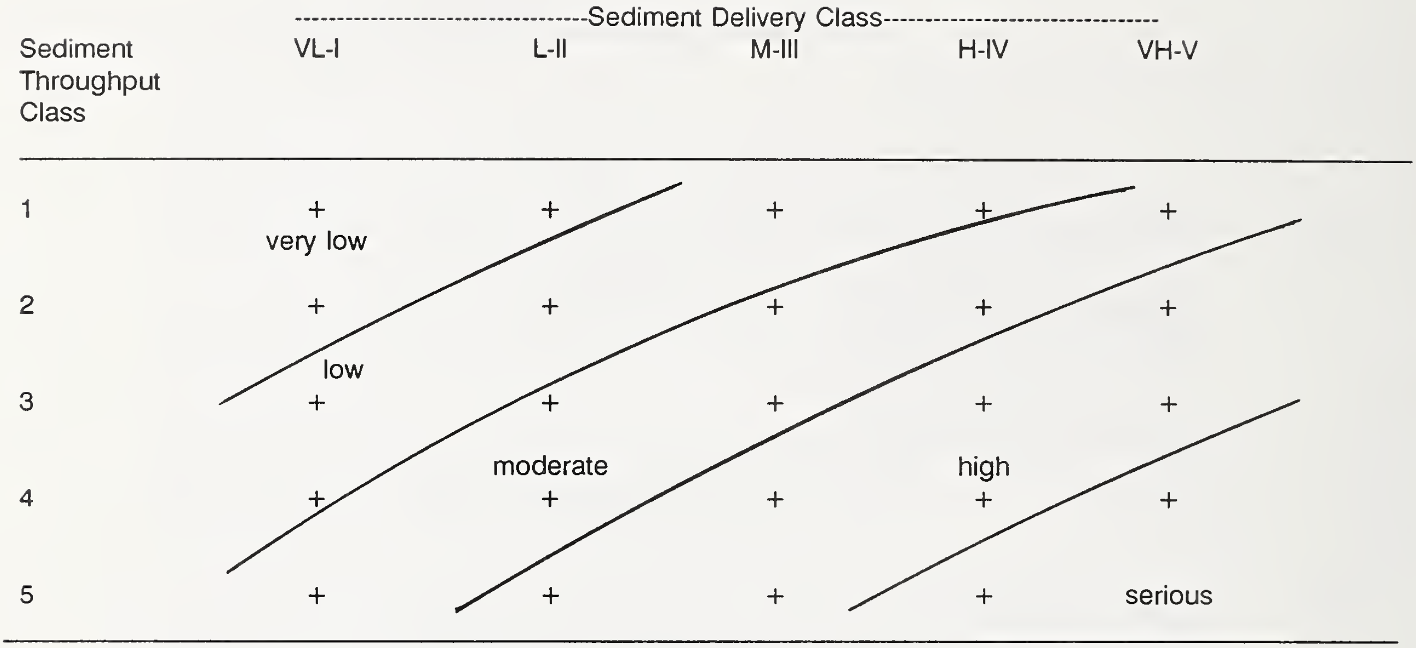


**Figure 5. Sediment transfer hazard matrix.**

determine the Sediment Transfer Hazard, and the sediment throughput map is used to determine the sequencing of throughput classes - a critical factor in determining impact to the fisheries sensitive area.

In summary, Class 1a and 2a are the fisheries sensitive zones. Sediment entering any channel may be transfered downstream to this area if there is not a sediment sink such as a Class 1 or 2 channel between the sediment source and the 1a or 2a zones. If there is not a "sink", a "red flag" situation is indicated because the fisheries sensitive area is directly connected to a more efficient channel transport segment. Based on the level of concern, the situation may require special road construction or harvesting methods to reduce sediment production, or in more extreme situations it may be necessary to call in a specialist to examine site specific features, or avoid forestry operations in the specific subbasin or polygon unit. If sediment produced on a site will not impact fisheries habitat, the decision to proceed with forestry activities is essentially a question of potential forest site loss.

## Conclusions

The Sediment Transfer Hazard Classification System provides the link between erosion and downstream sedimentation impacts on fish habitat. The system does not provide absolute quantities of sediment delivered. The quantity of sediment delivered depends on precipitation, soil moisture and streamflow conditions at the time of sediment production. These conditions are factors that resource managers must consider when they undertake activities on areas that are linked to fish habitat.

The link between erosion and fish habitat is critical for true integrated resource management. The system uses information that is available, or can be generated quickly and cheaply at the operational level. The cost of applying the system is minor considering the costs of not harvesting "safe" timber, or costs associated with attempting to rehabilitate damaged fish habitat.

The system was applied to a watershed in northwestern British Columbia that has high forestry and fisheries values. The hazard map significantly increased the confidence of resource managers in the planning exercise. Areas of concern in the watershed were clearly identified. Special attention will be paid to stream crossings and harvesting activities in these areas. Special measures such as revegetation of disturbed areas were prescribed. A significant outcome of the application was a clear recognition that erosion can be linked to fish habitat. This is generally accepted in concept, but applying the Sediment Transfer Hazard Classification System made it a reality.

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# A Method to Analyze Watershed Sensitivity

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***Abstract.*** This paper is intended to describe the method that was used for determining Watershed Sensitivity in the Supplemental Environmental Impact Statement (SEIS) for North Kulu Island. We are currently using this method as an analysis tool for several other environmental documents. It uses data available in the GIS for the Tongass National Forest and develops an empirical rating of the relative sensitivity of a watershed to potential management related impacts. Prescriptions for the proportions(percent) of watersheds to harvest in any 20 year period are developed that reflect both the Value of the watershed as well as its Sensitivity. The method is simple and easy to use, requires only limited amounts of data, and provides a reasonable basis for weighing watershed resource values.

## Background

Beginning with the release of the Southeast Area Guide in 1977 (USDA Forest Service, Alaska Region, Tongass National Forest), we began to evaluate the proportion of watersheds harvested using a 25% disturbance guideline. Used as a general guideline, it is thought that harvesting in excess of 25% of a watershed in the first entry may create demonstrable changes in low flow regimes. Though studies designed to determine the actual values at which changes in flows occur are inconclusive, the concept of using the proportion of the watershed disturbed as an evaluation tool is easy to use and has been incorporated into major EIS documents for Southeast Alaska. Also, uniform distubance quideline applied to all watersheds may be inappropriate, since watersheds differ in their response to forest management due to differences in physical characteristics such as geology, soil type, steepness, channel morphology and drainage density.

The Stikine Area of the Tongass National Forest began evaluating sediment production from watersheds in a systematic manner in 1980. The process rated individual watersheds rather than applying a single blanket value and dealt with potential sediment production rather than flow regime. Watersheds with higher erosion potentials were expected to require a greater amount of mitigation to meet the same watershed resource standards as watersheds with lower erosion potentials, given the same amount of disturbance. The term "Watershed Sensitivity" was used to identify this concept.

The "Watershed Sensitivity" model is an ARC/INFO Geographical Information System (GIS) version of the watershed sensitivity concept. It was developed to address a concern identified by the USFS Stikine Area management team about the amount of harvest proposed for the northern part of Kuiu Island.

Long range plans had called for continuation of road network expansion, putting more and more of the area under active timber management. This allowed for dispersal of harvest activity over a larger and larger area during the next 10 to 15 years. This has the effect of minimizing the amount of disturbance in any one watershed. Dispersal of watershed disturbing development activities in aerial extent and in time is considered a good watershed management practice. Harvest plans were substantially changed however, due to proposed legislation that in effect required the Forest Service to develop alternatives that would place a larger portion of remaining volume into watersheds already partially harvested. By so doing we were concentrating harvests into the watersheds on North Kuiu rather than dispersing it into East Kuiu. To meet our timber supply obligation, we had to look at imposing more cutting units in areas we felt may have previously been harvested to their upper appropriate limits. The question posed was, "How much more harvest could the watersheds in North Kuiu absorb over a short time interval without incurring unacceptable watershed resource impacts?" After reviewing the possibility of using a simple clearcut adjacency rule (which states that clearcuts must be minimun distance from each other so as not to be considered a continuous unit) to obtain dispersal, we felt that there was still too much harvest proposed in a short time interval in many watersheds.

We needed a system which could be automated for consistency purposes (so that each parcel of land was analyzed the same way), that used data already in the GIS, minimized additional data input and collection, could be easily applied, and would be immediately implementable. We therefore chose to modify the original "Watershed Sensitivity" idea to incorporate the GIS data

base. We used index values which could be rated by our watershed personnel into four groups; extreme, high, moderate, and low. For our purposes this is both simpler and more reasonable than a definitive sediment model, given the paucity of sediment data. Though this method is dependent on watershed erosion characteristics, it parallels procedures for evaluating flow regime changes.

This method and others like it can provide general guidelines for the amount of timber harvest impact in any one watershed for a given amount of time, however it is not intended to provide site specific requirements or directions.

## Values Used

For reasons of simplicity and inconsistent data sets between various land units, we chose to use only two erosion factors for this analysis; one representing soils and one representing stream channels. The resulting Sensitivity Indices also are used with approximations of relative user value in determining prescriptive recommendations (see flow chart Figure 1). The soils inventory came from the Order 3 Soil Survey of the Stikine Area, Tongass National Forest, and the channel typing inventory was done in accord with the Alaska Region channel typing procedures. Both inventories were where compiled on 2 inch/mile orthophoto quarterquads and digitized into the GIS database.

*Soils*

We developed a Soil erosion Index value for each soil type, consisting of two factors, Soil "K" and Slope. The Soil "K" factor is a standardized index of erodibility (Wischmeier, 1978). We multiplied the "K" value of the soil layer expected to be exposed to erosion times the square of the slope gradient(%), to compensate for the disproportional increases in erosion expected with changes in slope. Soil units found on steeper slopes have correspondingly larger Soil erosion Indices (EI) than soil units with similar "K" values found on shallower slopes.

$$EI = K \times (\text{slope})^2 \qquad (1)$$

The values for EI range from 0 to 100.

For each watershed we calculated a mean EI weighted by area. This was accomplished by multiplying the soil unit's EI times the fractional proportion of the area it represents and summing them for all soil units within the watershed boundary (Eq. 2).

$$EI(\text{watershed}) = EI(\text{unit } 1) \times \textit{Area(unit 1)} + \ldots + EI(\text{unit } n) \times \textit{Area(unit n)} \qquad (2)$$

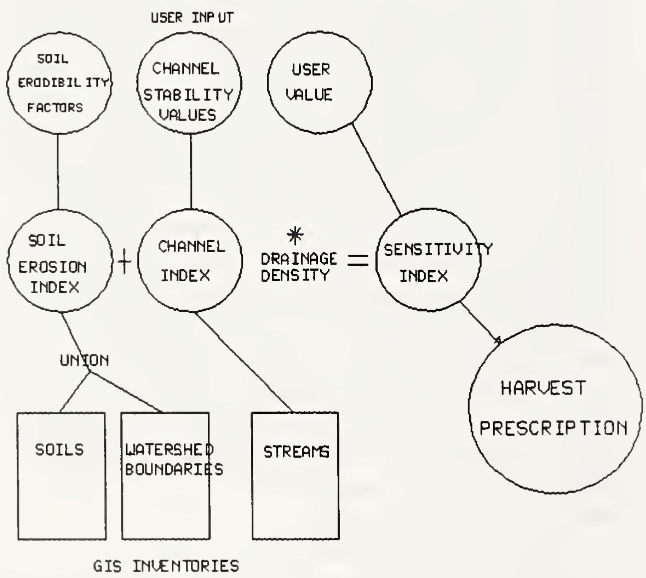


**Figure 1. A flow chart of the watershed sensitivity index (SI) process.**

*Channels*

To index the erosion potential of the stream network, we chose to use stream stability values collected by stream channel type (Pfankuck, 1975). Channel types are stream segments that exhibit similar gradient, width and substrate characteristics (Marion, 1987). Channel stability values measure the sediment potential of each channel type. They are more subjective than the laboratory standard "K" values used for the soils analysis, but data collection is standardized and maintained through training and field reviews. It is important to note that as channel stability values increase, the sediment production potential increases. A stream with a high stability rating has a higher sediment production potential than a stream with a low rating. Mean values range from 25 to 95 for channel types.

For each watershed we calculated a mean Stream Stability (SS) weighted by stream length, using the stream Channel Type Mapping available in the GIS data base. We multiplied the Channel Stability rating for that channel type times the proportion of the total length that that segment represents and summed the result for all channels mapped within the watershed boundary.

$$SS(watershed) = SS(strm\ 1) \times \mathit{Lngth(strm\ 1)} + \ldots + SS(strm\ n) \times \mathit{Lngth(strm\ n)} \quad (3)$$

A combined watershed erosion value was generated by adding the soils and channel values, Elw + SSw. This simple addition gives a disproportional weight to the channel component considering its actual surface area, as both numbers are similar in magnitude. We felt that the closer proximity of the channels to the water resources user compensates fully for any disparity based on surface area; therefore a roughly equal proportion between soil and channel factors is reasonable. It is also felt that, in general, the stream side environment has a more immediate effect on the water resource than the up-slope surface erosion potential.

*Sensitivity Index*

The combined erosion term (Elw + SSw) was multiplied by the Drainage Density (DD) (miles/square mile) to produce the Sensitivity Index (SI). Drainage Densities were developed from the same GIS data base used to calculate watershed area and channel length. We assumed that watersheds with higher drainage densities transport water and other materials better than watersheds with lower densities. We used the drainage density factor to represent the different efficiencies of the various watersheds to express the average erosion factor (Elw + SSw) directly to the water resource users. We feel that given the same erosion factor (Elw + SSw) the water resource values of a low drainage density watershed will be less impacted than a similar watershed with a higher drainage density.

$$SIw = (Elw + SSw) \times DD \quad (4)$$

For North Kuiu the Sensitivity Indices values range from 30 to 2000.

## Sensitivity Classes

Following our objective to simplify as much possible, we broke the SIw into four Sensitivity classes, low, moderate, high, and extreme. We rated the SIw based on our combined experience. Because of the time constraint we were working under, we only used the initial 371 watersheds in the Kuiu Study area to establish our sensitivity classes. Even though the study area is rather small, it contained a few examples of both very stable and extremely unstable watersheds relative to the Stikine Area. Reviewing the watershed maps, the SIw's, and our field notes, we assigned one of the four classes to each of the 371 watersheds (Fig.2). We reviewed them in detail to satisfy ourselves that the classes were responsive to the areas we were familiar with, and graded from class to class along well defined geologic/landform breaks. The class break values developed were; low (0-149), moderate (150-234), high (235-369), and extreme (>370).

Small watersheds tended to have more extreme SIw due to less internal averaging of slopes and channel stability values. This in itself is not a problem. We felt, however, that comparing these extreme SIw to SIw from the larger watersheds was not appropriate. These systems also tend to be too small in area for meaningful consideration in the planning process and do not normally support sufficient water resource values to justify harvest dispersion ommensurate with high sensitivities. Therefore further refinement was made by selecting against watersheds that did not have any stream depositional or transport channel types. We also narrowed it down to only those watersheds with cataloged salmon streams based on Alaska Department of Fish and Game (ADF&G) inventories (Fig. 5). Figures 3 and 4 are scatter diagrams based on the two refinements and showing that watershed sensitivity increases as watershed size decreases. Small watersheds were initially considered only because they existed on the watershed cover in the GIS and may not even be mapped in the other two Areas of the Tongass. Table 1 shows the relationship between larger watershed size and smaller sensitivity indexes.

**Table 1. Sensitivity Index and watershed size.**

| | Number of Watersheds | Average SI | Average Watershed Area |
|---|---|---|---|
| | n | | acres |
| All Watersheds | 371 | 342.7 | 678.2 |
| Watersheds With Valley Bottom Channels | 250 | 275.4 | 945.9 |
| Salmon Stream Watersheds | 113 | 245.3 | 1,594.3 |

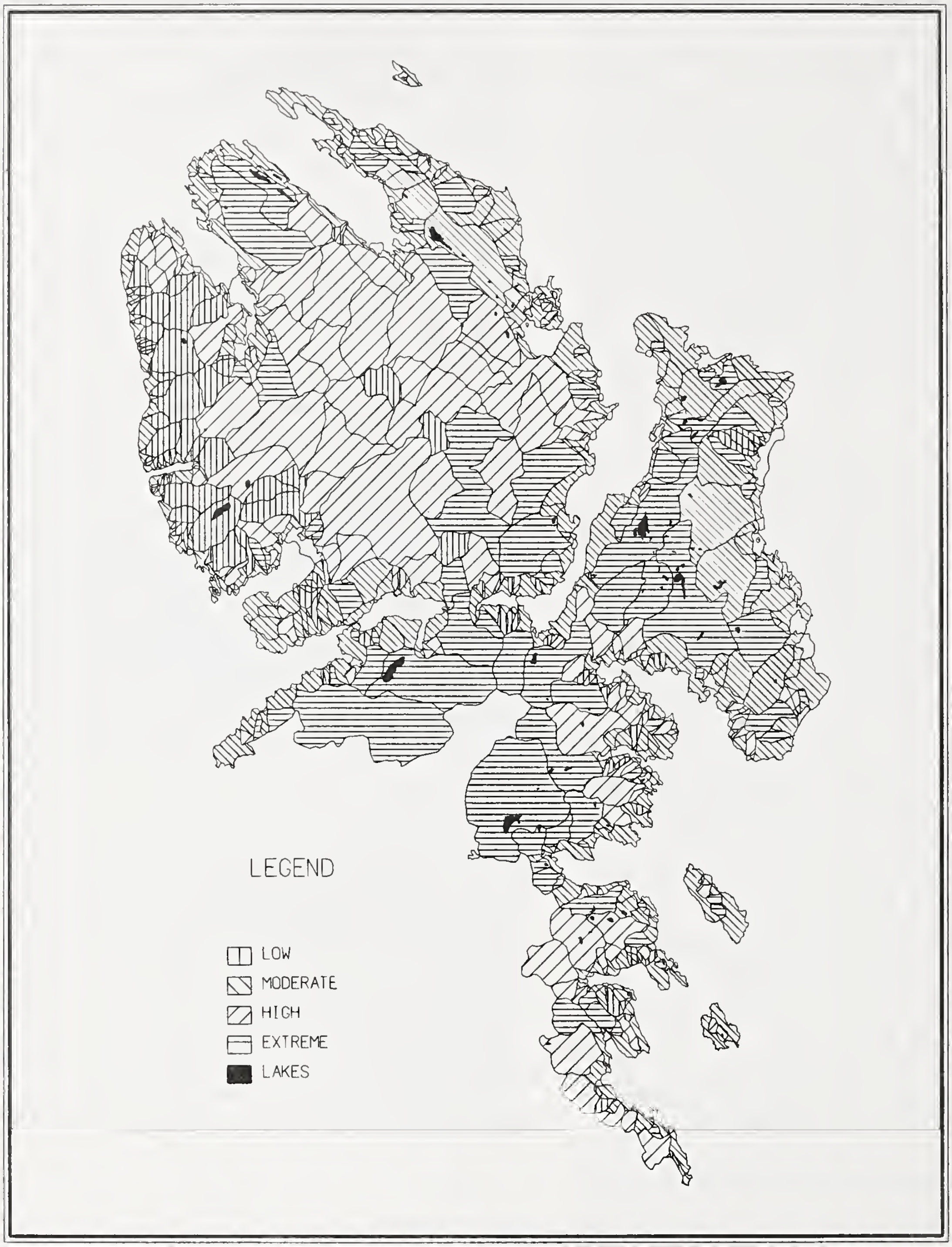


**Figure 2. Sensitivities of all North Kuiu Watersheds.**

### Users

Based on past management history and common sense we decided that given the same erosion potential we would tolerate less risk of water resource impacts with a high user valued drainage than we would with a low user valued drainage. If two watersheds had similar Sensitivity Indices but one was a city water supply and the other one had little or no known fisheries or other water user value, we could accept a greater risk of im-

pacting water quality in the drainage with the lower user value than we could accept with the city water supply. We interpreted this as allowing more harvest to occur in watersheds with low user values and less harvest in watershed with greater user values. We therefore proposed that high valued watersheds receive a lower percentage of harvest than watersheds with lower values, if both have the same Sensitivity Index. We proposed four user classes very-low, low, moderate, and high based primarily on anadromous fish use. All Alaska Department of Fish and Game (ADF&G) numbered streams were rated in accordance with Appendix E of the ADF&G input to the Land Management Plan (March 11, 1977) and listed as low, moderate, or high. The Rowan Bay Camp water supply stream was identified as high. All the remaining watersheds were classified as user class very-low, i.e. they receive little to no anadromous fish use.

## Application

We then developed a four by four Classification/ Harvest rate matrix, Threshold of Concern (Table 2). This reflects not only the ability of a watershed to absorb the impacts associated with harvesting but also its ability to respond to different water resource user needs. Several assumptions were used to help analyze harvest impacts on watersheds in a simplified and standardized way. They are: 1) High hazard soils are not planned for harvest. 2) Protection measures for riparian areas will be applied along all active stream courses. 3) The harvest methods will be almost exclusively cable yarding. These assumptions allowed us to analyze the effects of timber harvest on basically homogeneous watershed resources. We reviewed several of the ADF&G streams rated as moderate or high user classes that the interdisciplinary team (IDTeam) felt had been harvested to an "uncomfortable" degree to develop this matrix. We reviewed the percentage harvest acreage in those watersheds and set the threshold percentages at or below these percentages in the table. The IDTeam filled in the rest of table calling on their 61 years of combined timber, soils, hydrology, and fisheries experience on the Stikine Area. In this way, we were basing the percent harvest allowed in watersheds on information that we had on watersheds that were already harvested to what we considered to be the threshold of concern.

This table was presented to the Forest Management staff, along with an explanation of the methodology, and the time frames for implementation. The procedure was adopted and used to evaluate the alternatives in the Supplemental Environmental Impact Statement for Kuiu Island.

**Table 2. Watershed Threshold of Concern.**[1]

| | Watershed Sensitivity Rating (SIw) | | | |
|---|---|---|---|---|
| user value | extreme | high | moderate | low |
| •high | 10% | 20% | 25% | 35% |
| •moderate | 20% | 30% | 40% | 50% |
| •low | 40% | 50% | 60% | 70% |
| •very low | 70% | 70% | 80% | 80% |

[1]Threshold of concern values are the maximum amount of harvest (percent of the watershed) recommended for harvest over a 20 year period.

It should be noted that timber has rarely been harvested in acreage percentages greater than 40 in any given entry on the Stikine Area, since the early 1970's. Two of the controlling factors in reducing these levels are clearcut size and adjacency. Also the average operable commercial forest land (CFL) for the study area is about 50%. None of the few examples that we could find of small watersheds receiving over 50% initial harvest were found in the Kuiu study area.

In the Kuiu study area no sub-watersheds were developed except for Kadake Creek. It was broken into three sub-watersheds based on 3rd order tributaries because of its size. As a general tendency the larger the watershed the greater the variation within and the smaller the variation between. Small watersheds have greater variability and as the Classification/Harvest rating was anchored by larger watersheds with streams identified by ADF&G, applying the Threshold table to small watersheds should be approached with caution.

## Cumulative Effects

The Thresholds of Concern values (Table 2), can be used for developing estimates of cumulative effects. Lacking information on the length of time required for watershed recovery following harvest, to some known preharvest condition, is the difficulty in modeling cumulative effects. This model assumes that watersheds regain at least 50% of their erosion and water processing capabilities within the first decade following harvest. This coincides with silviculture recovery rates. We propose a model that operates on decade time intervals. The first decade would not be counted as contributing

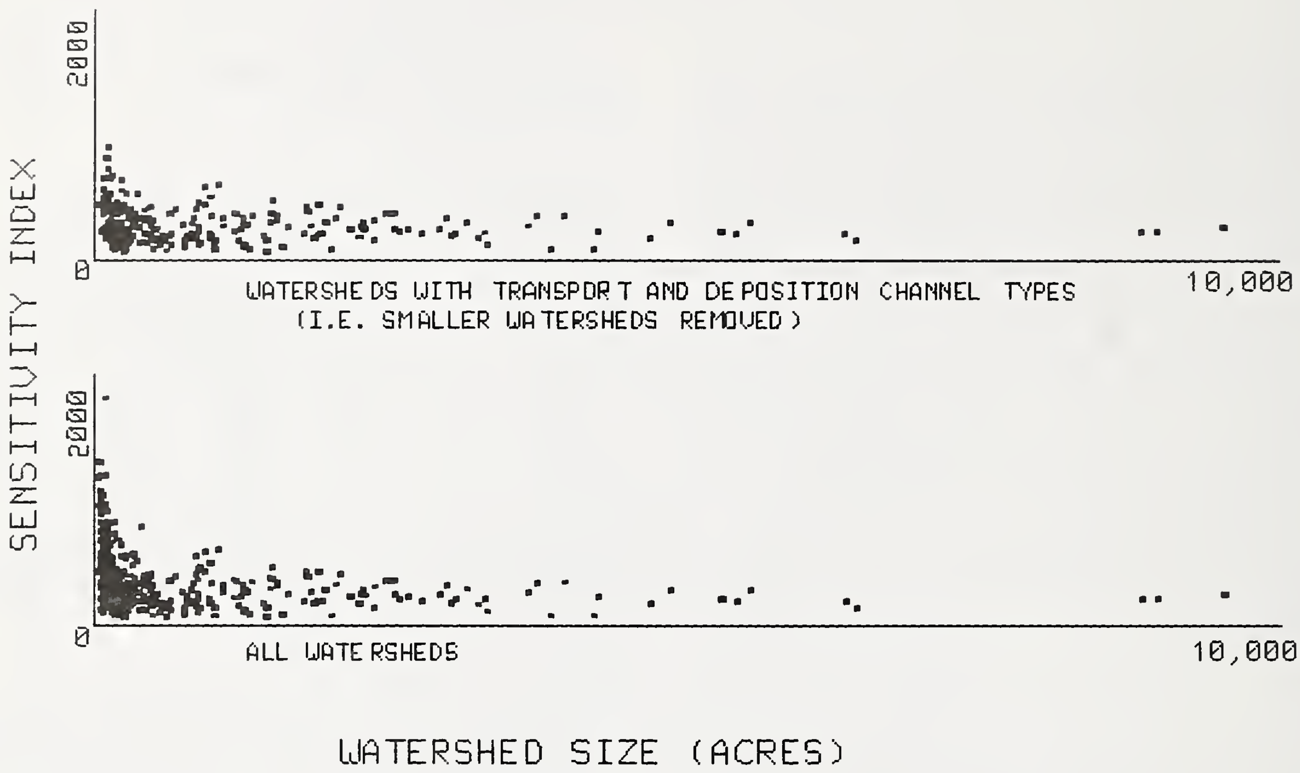


Figure 3. Watershed sensitivity (SI) in relation to size - larger watersheds.

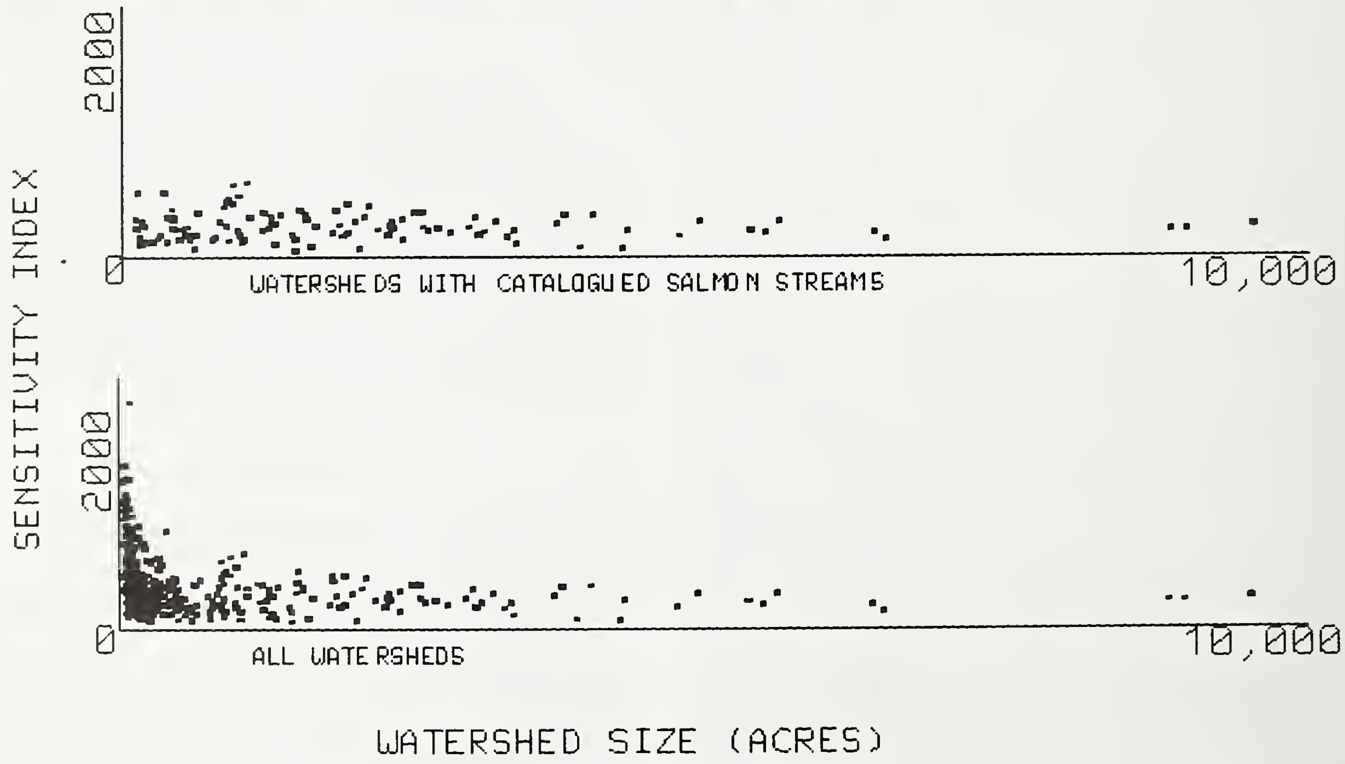


Figure 4. Watershed sensitivity (SI) in relation to size; Watersheds with catalogued salmon streams.

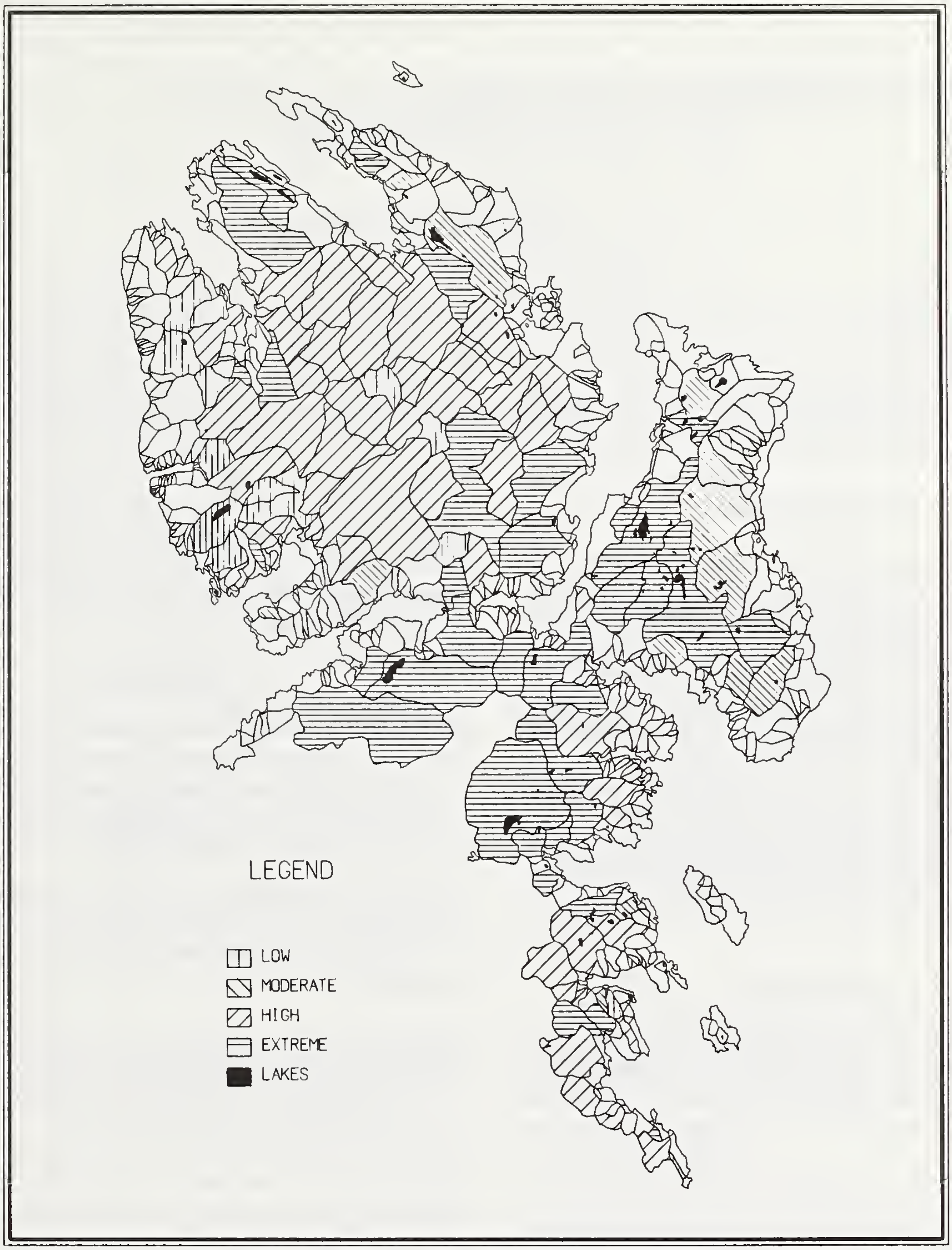


**Figure 5. Sensitivities of North Kulu watersheds with salmon streams.**

to recovery as harvest in a drainage can often take place throughout most of a decade in a given harvest entry. It would be considered as being newly harvested throughout that decade.

The effect of the harvest, as measured by percentage of area harvested, would decrease by 50% during the next decade. The third decade again decreases the effect by 50%. This is a half-life model and is easily programed or run on standard computer spreadsheets. An example is given in Table 3.

Table 3. Watershed recovery following harvest; an example.[1]

| | Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 |
| | portion of watershed (%) | | | | | | | |
| Prescription | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Area Harvested | 0 | 15 | 0 | 0 | 10 | 0 | 0 | 14.6 |
| Unrecovered | 0 | 0 | 15 | 7.5 | 3.3 | 11.6 | 5.8 | 5.4 |
| Available | 20 | 5 | 5 | 12.5 | 7.4 | 9.4 | 14.2 | 0 |

[1]The recovery is not modeled until the second decade following the decade in which the harvest is planned to occur.

## Recommendations

We feel that this model has merit and can be modified to improve its responsiveness where necessary. Some form of spatial analysis is the next thing to examine for inclusion. This may slow the processing time down somewhat but would improve reliability and confidence in the result. One of first things to look into would be using actual spatial slope position to calculate the Soil Erosion Index (EI) for the individual soils units. The next item on the list would be accumulate the effects based on where the harvest units were situated in the watershed, on what type of soils and slope, and riparian zone impacts. Variable Source Area hydrology models could be incorporated using these spatial characteristics too.

## Conclusions

Application of this modeling method provides a reasonable basis for land management decision makers to weigh the values of water resources in considering alternate possibilities for managing timber resources. In its present form the model is simple, and easy to use and explain. The processing time required is minimal for the level of analysis produced. The model appears to be very robust and may be modified to include spatial characteristics.

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# Hydrology of the Skeena River Floodplains I: Implications to Herbicide Use

*P. G. Beaudry*

*B. C. Forest Service, Smithers, B. C.*

***Abstract.*** This study was initiated to provide information to silviculturists and concerned members of the public about the environmental characteristics of the Skeena River floodplains that affect the fate of forestry herbicides. This paper describes 1) the annual groundwater regime and its driving forces, 2) the stratigraphy of the deposits, 3) the physical characteristics of the soil, and 4) the climatic regime of both air and soil. Based on these data and the chemical and physical properties of certain herbicides, inferences are made about their probable fate in coastal alluvial environments. The period late July to early September is identified as the safest for the application of herbicides as the water table is low and consequently the chances of flooding are low. The surface deposits of fine silts and the rapid incorporation of organic matter into the soil should ensure low mobility of most herbicides.

Coastal floodplains are among the most productive ecosystems in British Columbia (Roemer et al. 1988). Although many of these sites once supported thrifty stands of Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*), post-harvesting neglect or unsuccessful silviculture treatments have left a legacy of unmerchantable stands of red alder (*Alnus rubra*) and Sitka willow (*Salix sitchensis*). The rehabilitation of these stands, to Sitka spruce and black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), is a priority for operational silvicuturists. While these sites are valuable, they are inherently complex to manage because of 1) the potential for severe vegetative competition, 2) their high value as fish and wildlife habitat, 3) the potential for recreational conflicts, and 4) extensive seasonal flooding.

Application of herbicides, following rehabilitation programs, is one of the vegetation management strategies used to control undesired vegetation on these floodplains. Although usually considered the most cost-effective, this strategy is often not the most popular, especially where there are potential conflicts with other resources.

This project was initiated in response to public and other agency concerns about some research involving the herbicide Garlon 4 on the Skeena River floodplains. The project was initially designed to: 1)learn about the groundwater regime and to study the potential for groundwater contamination by the experimental herbicide Garlon 4, and 2) describe the characteristics of these floodplains that affect the environmental fate of herbicides (i.e., soil and climate).

## Methods

### *Site*

In 1983, Forestry Canada (F.C.) began a program to test the efficacy and environmental fate of Garlon 4 in coastal floodplain environments of British Columbia. In response to public concern, I was asked by F.C. to describe the groundwater regime and the environmental characteristics that affect the fate of herbicides on these floodplain sites.

The site chosen by F.C. for monitoring environmental fate of Garlon 4 was at the confluence of the Kasiks and Skeena Rivers, between Terrace and Prince Rupert (Fig. 1). Along with the groundwater monitoring, the program included 14 other environmental testing projects.

Intense public pressure lead to cancellation of the experimental spray of Garlon 4. Because my project was already well advanced and deemed valuable in supplying baseline information for the management of coastal alluvial sites, it was continued.

### *Groundwater Regime*

To describe the groundwater regime at the study site, 58 groundwater wells and piezometers were installed in numerous transects and networks. Forty of these were installed in an intensive network on both sides of an active backchannel. The networks were designed to describe localized groundwater flow from the site of the planned Garlon application to the backchannel. Regional flow was described with an additional 18 piezometers in a more extensive network which crossed the entire floodplain (Fig. 2).

In the intensive network, I installed 12 piezometer nests, each nest consisting of two or three piezometers. Within the nest, the piezometers were dug to a depth of one, two and three meters (if depth to the gravel layer

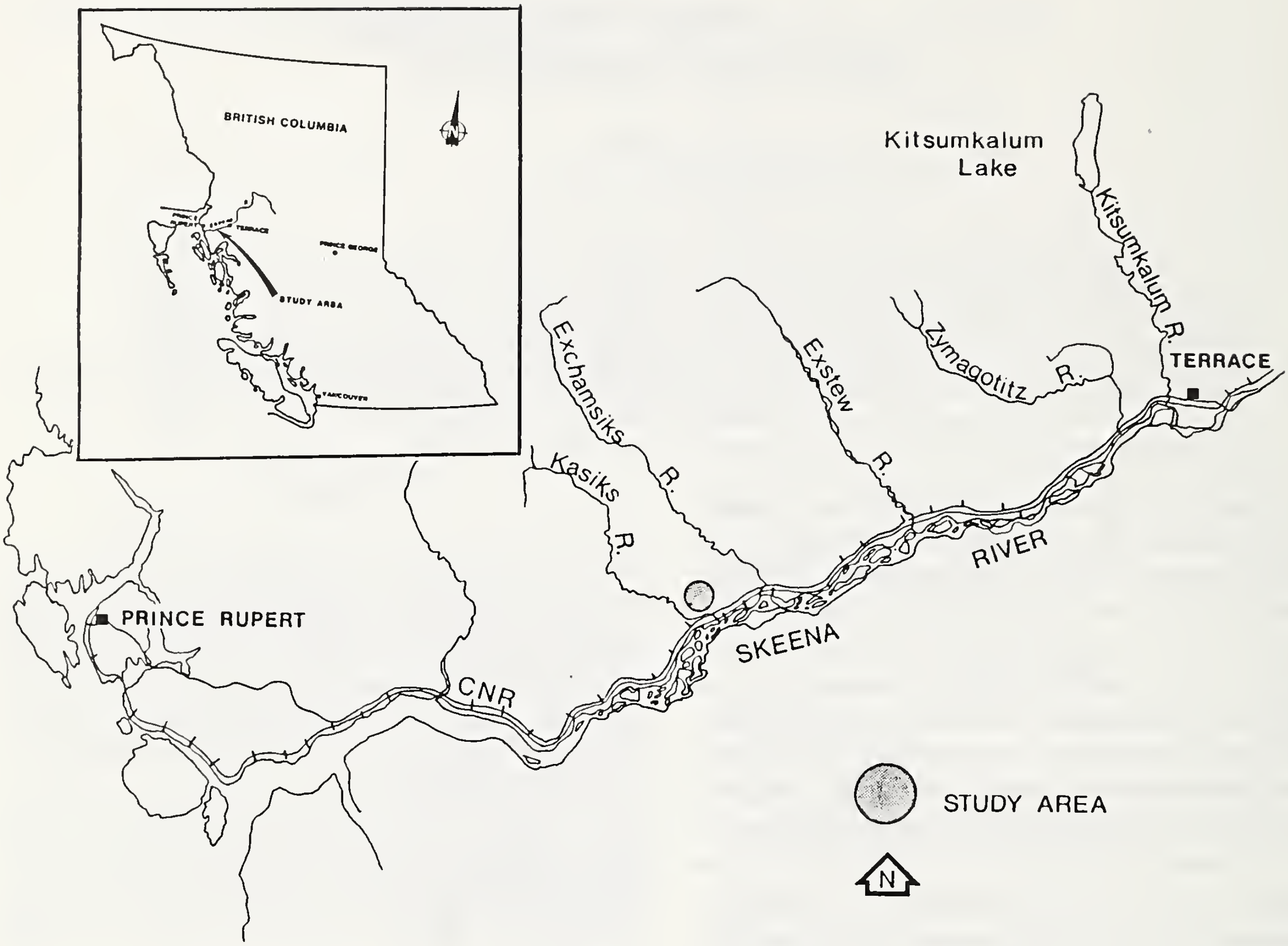


**Figure 1. Location of study site.**

permitted it). I located the nests to obtain information about both horizontal and vertical groundwater movement. Also, seven wells were installed between the nests to determine the height of the water table. These wells were dug down to the gravel layer and varied in depth from 1 to 4 meters below the surface. I also used "mini-piezometers", made from 1/2 inch copper tubing 60 cm in length, to detect the presence of shallow perched water tables ( 20-30 cm below the surface).

The height of the water table was measured in the piezometers and wells with a customized electric tape measure. This tape measure (graduated in mm) was "wired" to signal when the conductive tip made contact with the free water in the well or piezometer.

The readings in all 58 wells and piezometers were made on a daily, bi-weekly, or monthly basis depending on the season and height of the groundwater. In addition to the manual piezometers and wells, 4 piezometers were equipped with a recording height gauge connected to continuously recording data loggers. For two years, heights of the Skeena River were recorded manually in conjunction with the readings of the piezometers and wells. In 1988, I installed a continuously recording height gauge in the Skeena River to more accurately track the relationship between river heights and groundwater regimes.

A topographic survey was done using survey levels to determine the relative heights of all the piezometers and wells and the ground surface where they were located. Pump tests were also performed in several of the piezometers to determine hydraulic conductivities of various layers of the soil. A flow net analysis (Freeze and

Cherry, 1979) was used to determine the velocity and direction of groundwater movement at various times of the year.

*Soils*

Eight standard soil pits were dug and fifty-one soil samples were cored for analysis of hydrologic characteristics. A soils laboratory was contracted to determine the following on the cored samples: 1) organic matter, 2) bulk density, 3) effective porosity, 3) particle density, 4) saturated hydraulic conductivity, 5) air entry tension, and 6) the volumetric water content at 5 tension levels.

*Stratigraphy*

A nested design is most appropriate for characterization of the spatial distribution of the stratigraphy of alluvial deposits (Schreier, 1987, Pers. Comm.). Accordingly, I conducted sediment sampling at two spatial scales. At the intensive level, 30 samples were collected on grids 10m x 10m. To cover the larger scale, samples were collected every 50 m along a 1 110 m transect and a second 750 m long transect (Fig. 2). I did the sampling using a 2.2 m long Oakfield soil sampler and recorded all layers present in each core.

*Climate*

I used an automated weather station to measure: 1) snowmelt and precipitation rates, 2) air and soil temperatures, 3) water table fluctuations, 4) soil moisture, 5) relative humidity, and 6) solar radiation. These data were collected on an hourly basis for three consecutive years (1985-1988).

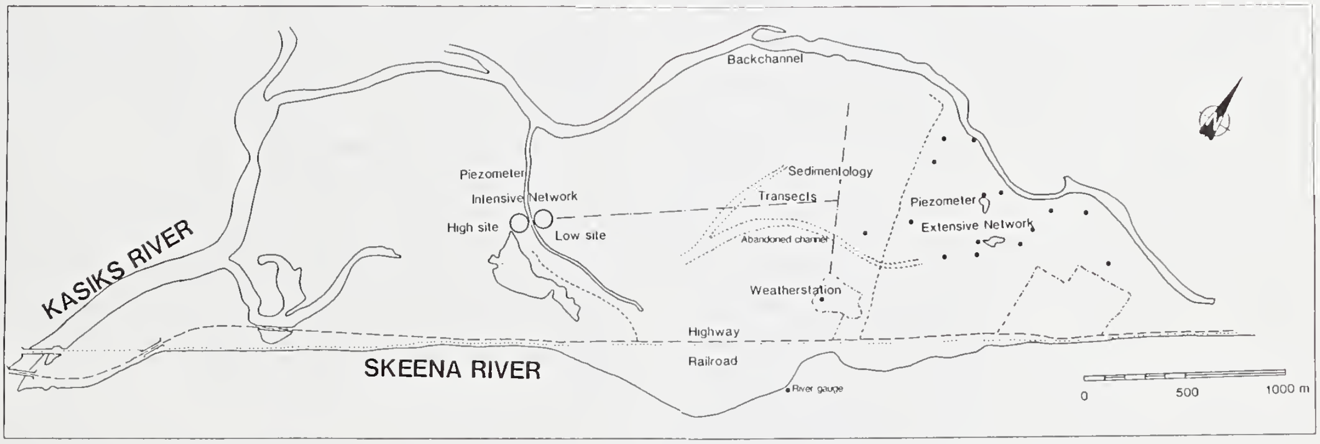


**Figure 2. Location of piezometer networks, weather station and sedimentology transects.**

## Results

*Soils and stratigraphy*

The soils of the Skeena floodplain are typical alluvial deposits formed by the successive deposition of gravels, sands, and silts. The stratified layers are most often discontinuous, thus forming a heterogeneous medium. The surface layer is generally a well structured, porous silt overbank deposit. Below this can be found several layers of much denser silts and sands of low hydraulic conductivity. The depth of surface organic material (LFH) is minimal (0-3 cm) on these rich sites, and deciduous litter, active fauna, and rapid decomposition predominate. Decomposing roots are the main source of buried organic material. The organic matter content in the top 10 cm of mineral soil is on the average about 3%, with a range of 1.5% to 7%. A representative diagram of the soil characteristics of these floodplains is presented in Figure 3.

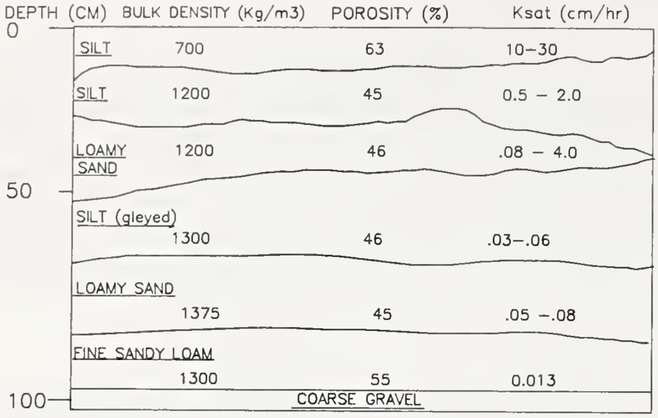


**Figure 3. Typical profile of the Skeena River alluvial deposits.**

*Groundwater Regime*

Following 2 years of groundwater, river, and climate measurements, I was able to describe the flooding processes of these sites and their relative importance to one another. These flooding processes include: 1) groundwater rise, 2) ponding, 3) perched water tables, and 4) overbank flooding. The fluctuations of the groundwater are directly associated to fluctuations of the Skeena River. The main characteristic of the groundwater and river hydrographs is the double peaks that occurs annually (Fig. 4). Although this site is coastal, it is subject to a combination of interior and coastal type hydrographs; this causes the double peak. The first peak (spring) results from high elevation snowmelt occurring over the entire basin. The second peak (fall) is rain-generated. This is caused by heavy rainfall over large portions of the basin.

Groundwater fluctuations, although directly driven by the Skeena River, lag both in time and amplitude with the river fluctuations (Fig 5). The further inland from the river, the larger the lag. Consequently, high groundwater levels can only result from sustained high levels of the river. This process is illustrated using the 1988 data (Fig. 5). The sustained high flows of the spring are able to drive the water table to the surface, flooding many low-lying areas (schematically presented in Fig. 6a & b). Although the fall flows are often higher than the spring flows, the water table usually does not reach the surface in the fall. This rise in the water table may not be high enough to cause flooding, but it can impede drainage and cause shallow lateral flow.

Saturated flow can also occur from the surface downward. This happens in response to localized events such as rapid snowmelt and intense rainfall. A perched water table forms because of the higher density and low hydraulic conductivity of some of the near-surface sand and silt layers (Fig. 6c). Under these conditions, I frequently observed substantial lateral movement of water through small root channels and worm tunnels. This flow of water occurs at the interface of the low density surface silts and the much higher density silts, loams, and sands (Fig. 3).

In addition to a rising water table and poor drainage, flooding occurs from river water overtopping the banks (Fig. 6d). On many sites, this overbank flooding occurs several times a year causing extensive inundation. The duration of inundation depends on the local relief (i.e whether the surface waters can drain laterally or whether they pond on the site).

*Soil Climate*

Soil temperatures and soil moisture data indicate favourable conditions for microbial degradation of herbicides during non-flooded periods between May and October (Table 1).

**Table 1. Average soil temperature range at study site (May - Oct 1987).**

| Vegetation Cover | 5 cm depth | 10 cm depth | 15 cm depth | 20 cm depth |
|---|---|---|---|---|
| | ----Celsius---- | | | |
| Complete alder canopy | 12-17 | 12-16 | 12-15 | 14-15 |
| Bare soil | 10-34 | 12-27 | 14-23 | 15-18 |

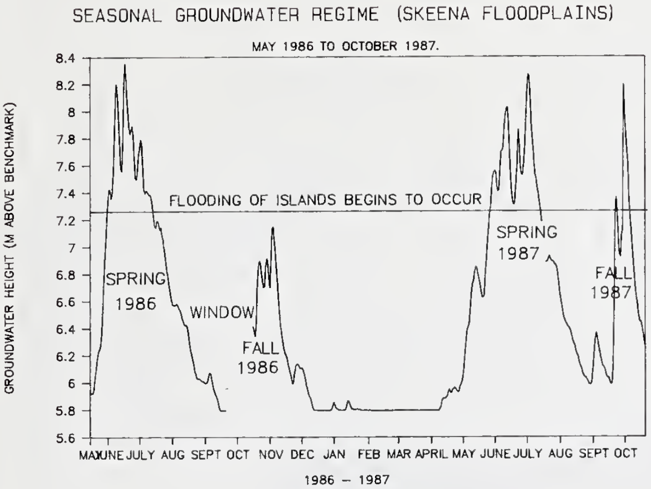


**Figure 4. Groundwater regime, 1986-1987, showing flooding of islands.**

Because of the wet climate, soils are maintained close to field capacity for much of the growing season. During the 1988 growing season, soil water tension never increased above 0.5 bars. In 1987, soil water tension remained below 0.5 bars for all but 2 weeks in early August, when bare soil surface maximums reached 1 bar.

Although the soils do not usually freeze in the winter, as they are well insulated by a 1 to 3 m snowpack, they remain close to 1°C from November through to April. These conditions are not favourable for microbial degradation or photodegradation of herbicides. Thus, herbicide residues would no doubt degrade slower in these soils than in warmer southern climates (e.g. The half-life of triclopyr was reported to be between 79 and 156 days for soils at 15°C, and less than 50 days for soils at 25 - 35°C (Ghassemi, 1981). The Dow chemical company reports a half-life (triclopyr) of 10 days in a silty clay loam and 46 days in a loam, both soils being at 35°C and soil moisture at field capacity (Dow, 1983)).

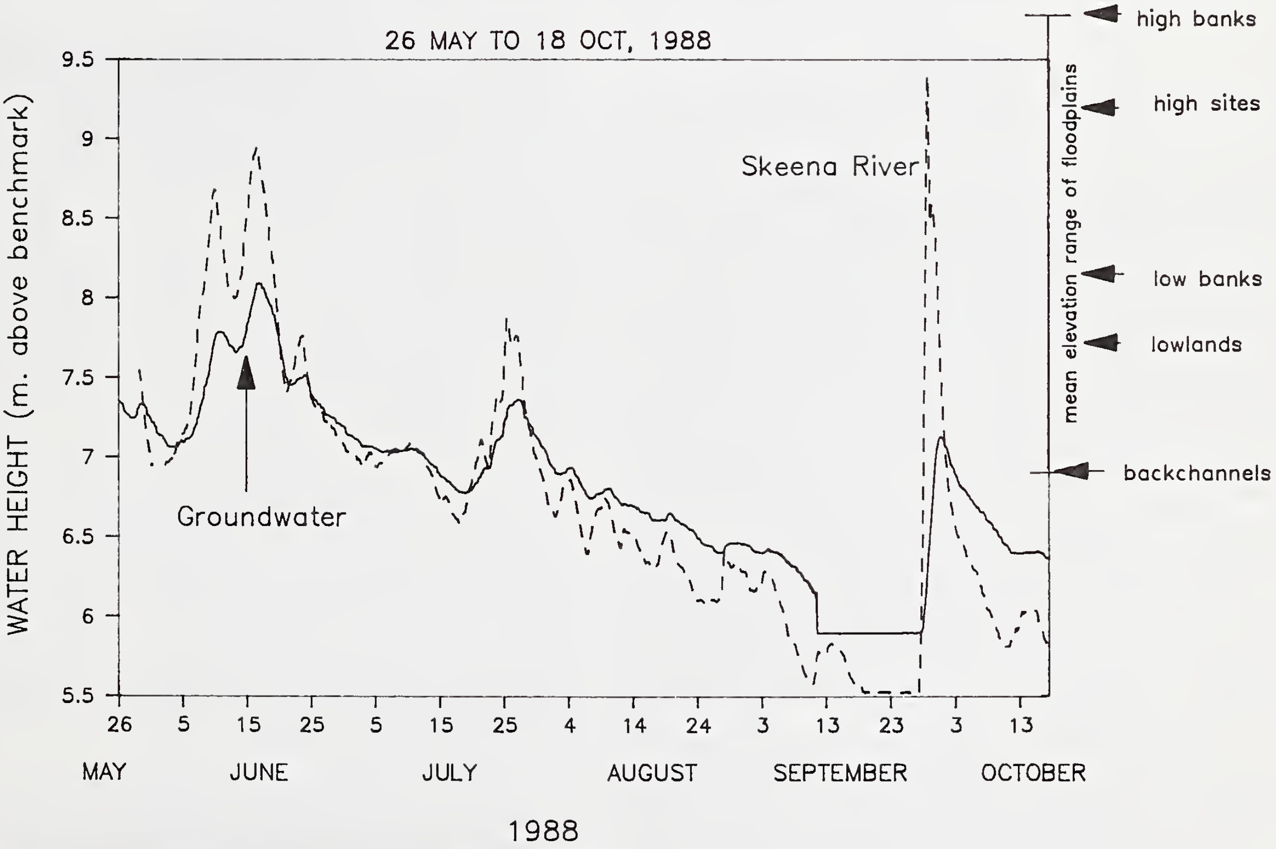


**Figure 5. Groundwater and river hydrographs, 1988.**

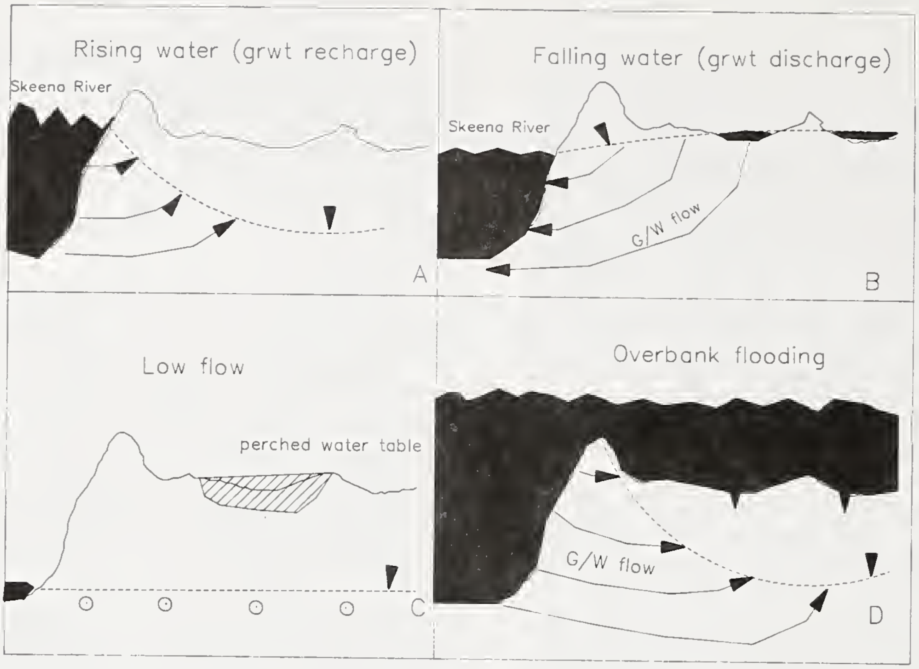


**Figure 6. Relationship between river height and groundwater flow (obtained from flow net analysis).**

### Discussion

*The Fate of Forestry Herbicides on Coastal Floodplain Sites*

I have described the soil characteristics of the Skeena floodplain and the processes of groundwater movement and flooding. In light of this description, it might appear that several potential routes exist, on these alluvial sites, for off-site movement of herbicides. These routes could include: 1) mobilization of herbicides in surface waters as a result of groudwater rise or overbank flooding, 2) lateral movement in shallow lateral flow, and 3) deep leaching associated with groundwater recession. However, this paper has also identified periods ("windows") when the application of herbicides would result in limited movement, if any (Fig. 7). Thus, the application of herbicides (especially soil-mobile herbicides) should be avoided during and immediately prior to periods of high water tables and flooding. The periods to avoid include June-early July and October-November (Fig. 7).

The potential for vertical or lateral leaching of herbicides into groundwater or into protected water bodies is minimal on these sites. This is because the relatively fine texture (silts and clays) and organic matter content of the soils provide sufficient adsorption sites. The more adsorption sites there are in the soil, the greater will be the capacity of the soil to immobilize the herbicide molecules. For example, because of its strong adsorption characteristics, the herbicide glyphosate would certainly be immobilized upon contact with coastal alluvial forest soils . More mobile herbicides like 2,4-D (acid), hexazinone, and triclopyr may leach to some degree into such soils, but proper timing of application should minimize off-site movement.

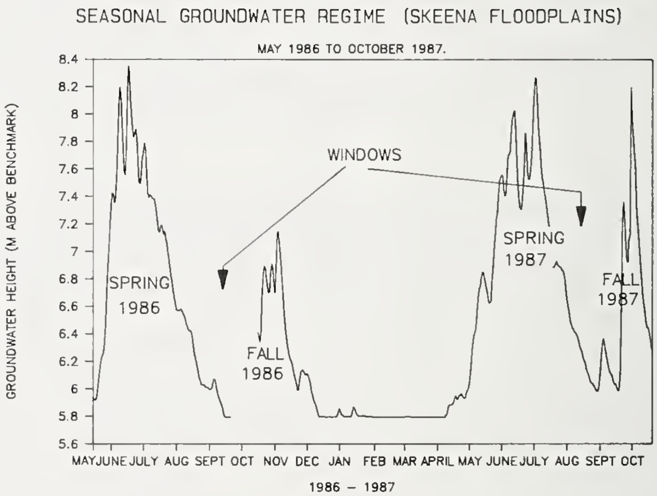


**Figure 7. "Windows" for application of herbicides to avoid off-site movement.**

## Acknowledgments

I would like to thank Mr. David Wilford, Regional Hydrologist, who provided considerable assistance with the initiation of this project. In addition I thank Mr. Dan Hogan who assisted with field work and provided many hours of thoughtful input to the development of the classification, Mike Larock for locating sites, providing logistical support and identifying the District concerns, and Mr. Dirk Septer for field assistance and compilation of data and the North Coast and Kalum Forest Districts. Financial support was provided by the Research and Development component of the Canada-British Columbia Forest Resource Development Agreement (F.R.D.A.) - project 2.11.


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# Hydrology of the Skeena River Floodplains II: Flood Hazard Classification for Silviculture

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***Abstract.*** This paper, based on the results of the baseline hydrological description of the Skeena River, describes a flood hazard classification for planning silviculture treatments on the floodplains. To develop the classification, survival and growth of Sitka spruce (*Picea sitchensis* ) were related to frequency, duration, and depth of flooding. Certain topographical and morphological features of the floodplain are identified as being unfavourable for the establishment and growth of Sitka spruce. Using 1:10,000 aerial photographs and a five-category frequency/duration classification, the user can identify site specific flooding potential. The morphological and topographical description of each class is included along with the potential for the class to grow Sitka spruce relative to flood hazard.

The extensive seasonal flooding that occurs on the Skeena River floodplains creates difficulties for the artificial regeneration of logged or rehabilitated sites. Silviculturists have noted a large variability in the success and growth of Sitka spruce within young plantations. Much of this variability has been attributed to the seasonal flooding, where poor growth and death of Sitka spruce seedlings occurs in the depressions and lower areas of the floodplains. The literature also provides evidence that prolonged flooding can be detrimental to the survival and growth of young Sitka spruce seedlings (Coutts, 1981, Coutts and Philipson, 1978; Philipson and Coutts, 1978, Grossnickle, 1987).

Some concerns and questions were identified by silviculturists about flooding and the regeneration of Sitka spruce, these were: 1) how often and how long do these sites flood? 2) is relative site elevation the sole criterion for determining flood hazard? 3) is there a critical relative elevation below which Sitka spruce cannot survive? 4) what is the relative elevational or other geomorphological difference between good and unacceptable growing sites? 5) can these sites be described and classified in the silviculture planning process so money can be spent in the most efficient way?

The information obtained from the study of the hydrology of the Skeena floodplains (Beaudry 1989) provided some baseline information for solving some of the flooding questions. To provide some better answers additional field work was done and more specific field data collected. Based on an understanding of the flooding processes and the relative frequency and importance of these processes, I thought it possible to devise a classification/mapping system that could highlight areas with high flooding hazard. This classification is aimed at improving the planning phase of rehabilitation programs and providing support for pre-harvest silvicultural prescriptions.

## Methods

The flood hazard classification, described in this paper, is based on the data obtained from the hydrological description of the Skeena floodplains (Beaudry, 1989) and some additional field work. My approach to developing a flood hazard classification for silviculture planning was to: 1) develop a working model on how the sites flood and the relative importance of these processes, 2) test the model by applying it to a case study, 3) field test the case study, 4) revise the classification as necessary, according to the field check, and 5) organize operational trials by field foresters.

The study of the hydrology of the Skeena River revealed several processes by which these islands flood. These different processes dictate the location, frequency, and duration of flooding. Using 1:10,000 aerial photographs I was able to identify areas subject to different flood hazards. These areas were classified into five categories, from frequent flooding/impossible to grow Sitka spruce to rare flooding/growth of spruce not affected by highwater. These classes were described according to topographical and geomorphological features.

To test the system, I mapped and verified flood hazard on several islands. The field verification consisted of determining how high the annual floodwater actually rose over various parts of the island. My basic hypothesis was that the height of flooding was closely correlated to seedling survival and growth.

In March 1988 numerous transects were established across the mapped islands and instrumented with flood height indicator stakes (110 locations). The flood indicator stakes were constructed of 1.5 m lengths of 1.5 inch PVC pipe cut in half lengthwise, creating a concaved shaped stake. The inside of the stakes were coated with a water soluble paint and the tops were capped. The stakes were inserted in the ground and on

an angle to prevent rainwater from washing away the paint. As floodwaters rose, the paint was washed off, leaving a high water mark on the stakes. I chose this design because it was inexpensive and light.

In August 1988 I returned to the islands and recorded the height of flooding for each individual stake. These height-of-flood data were mapped, then compared to the initial predictions obtained using the initial flood hazard classification. The field check identified certain weaknesses in the classification system and revisions were made accordingly. The revised classification is presented in the following section.

*Seedling Height-Ground Elevation Surveys*

In addition to the flood stakes, I installed a transect on Skeena Island 002 to determine the relationship between ground elevation and the height of recently planted Sitka spruce. This island had been logged, broadcast burned, bladed and scarified in 1982, planted with Sitka spruce plugs in 1983, manually brushed in 1984, and sprayed with the herbicide Roundup in 1986. A survey done in the spring of 1988 showed that the success of the plantation varied from one area to another. In some areas the growth of the seedlings was excellent, while in others the seedlings did not survive. This variation in the establishment and growth of the seedlings seemed to be best explained by flooding levels and hence ground elevations.

On the transects I measured total height of the seedlings and the ground elevation at the location of the seedlings using a survey level. All the elevations were established in relation to a 10m benchmark. I made 125 paired measurements of seedling height and elevation along the transect.

## Results

*Flooding Heights*

The Spring peak flows of 1988 were about average (B.C. Water Management Branch, Pers. Com.), but flood heights on the islands, as measured with the flood stakes, were much higher than I had predicted. I also noted, during collection of the flood stake data, that in some areas Sitka spruce growth was excellent, even though flood waters had almost inundated the seedlings. These data pointed out that depth of flooding was not the only variable that explained variation in seedling growth. Thus, the hazard classification system could not be based solely on predictions of flooding depths.

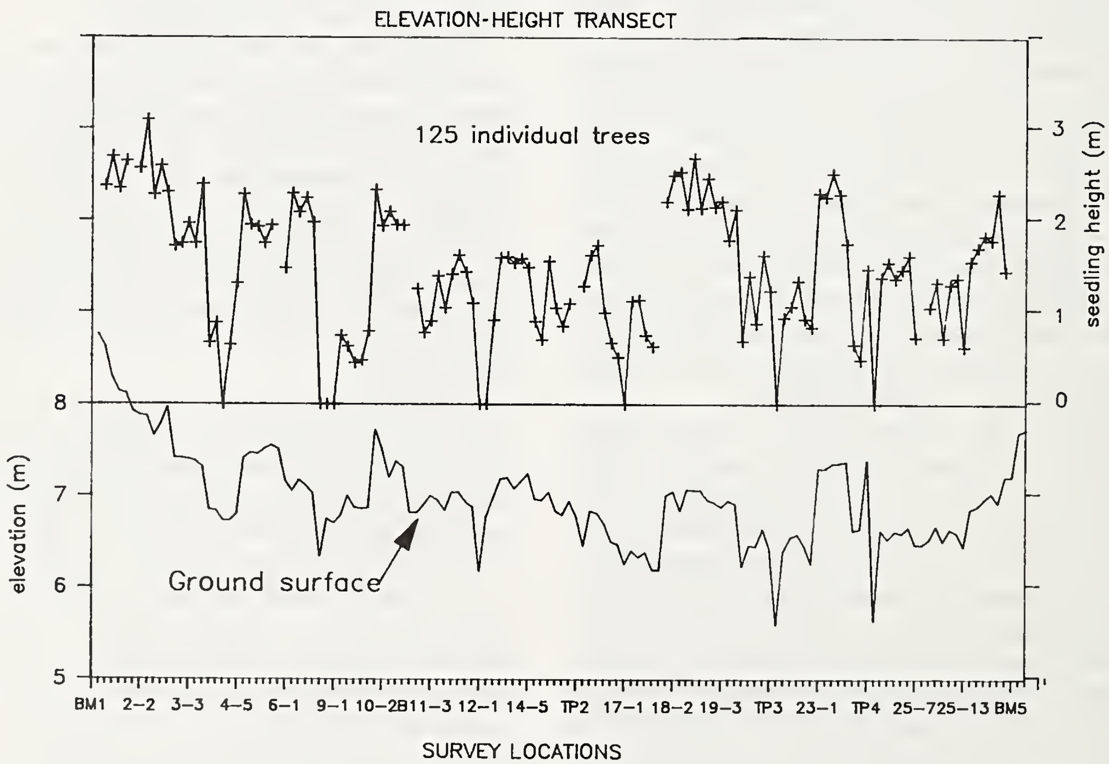


**Figure 1. Seedling height-ground elevation transect, Skeena Island 002.**

A significant relationship was obtained between the elevation of the ground and the height of the spruce seedlings. These data are plotted in Figure 1 in the same order as they were collected along the transect. It shows well that small gains or losses in elevation can have a substantial effect on the growth of spruce.

I also performed a linear regression analysis of tree height vs. ground elevation data to obtain a measure of the extent of the relationship (Fig. 2). The analysis rejected the null hypothesis, accepting the existence of a relationship at the 99% probability level. Ground elevation explains 53% of the variation in tree height ($r^2$= 0.53).

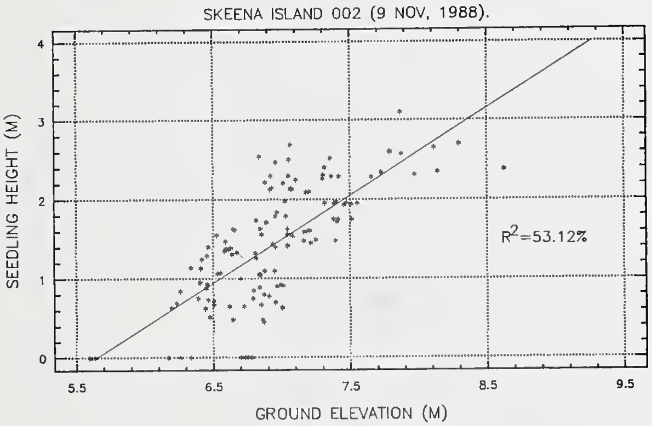


**Figure 2. Linear regression of seedling height over ground elevation.**

These results confirm those obtained with the flood stakes; i.e., although important, ground elevation does not, by itself, explain the success or failure of Sitka spruce growth. There are numerous other factors that no doubt have an influence. These could include poor planting, genetic variation, browsing, disease, pest, etc. However, from my observations I think that the variations in growth can be best explained by a combination of both depth and duration of flooding. Unfortunately, I had no direct measure of how long the seedlings were submerged.

To obtain an indirect measure of duration of flooding, I combined the river height data and the data on the elevation of various landscapes (Fig. 3). Those data show, for example, that the river height can be higher than the height of the lowlands for 20-30 days a year, thus seedlings located in these lowlands may have their roots in saturated soils for 20 to 30 days, or more, per year.

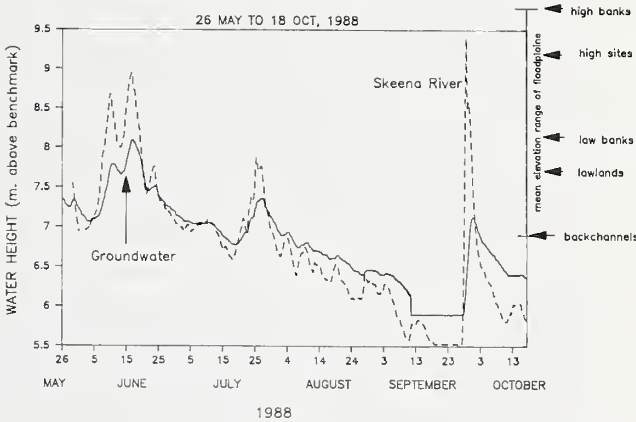


**Figure 3. 1988 groundwater and river hydrographs.**

In addition, I looked at floodplain morphology and identified features that affect duration of submergence. This involved studying both the flooding and the draining process. The most important flooding process is the overtopping of the banks (Fig. 4A), although the rising water table and impeded drainage also have consequences to spruce growth. As the river rises, its first opportunity to flood a site is via depressions in the bank. The river water flowing in through these depressions may follow an old abandoned channel or spread-out over the lowlands. As the river continues to rise, the higher banks get overtopped and most of the floodplain can become covered in water. The maximum stage height of the river determines the maximum depth of flooding. Of course the longer the river remains high, the longer the seedlings are submerged at maximum depth (an important characteristic of the spring floods). As the river drops, so does the height of flooding, until the height of the bank is reached. At this point, if there are no dips or depressions in the bank, the water becomes trapped inside the floodplain.

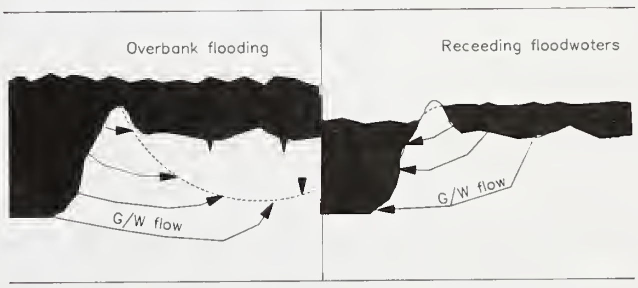


**Figure 4. Overbank flooding and recession.**

If the water table has risen close to the surface, drainage is impeded. Thus, the duration of flooding within certain areas of an island could be substantially longer than the duration of high river flows (Fig. 4B).

This leads to the definition of two important landscape features in relation to duration of flooding (features which are easily identified on aerial photographs): 1) The low areas that are **"open"** at one end, allowing free drainage of flooded waters (e.g. abandoned backchannels) and 2) the low areas that are **"closed"** to direct drainage back to the river. These two landscape features can be at the same elevation, but because of their "open" or "closed" nature the duration of flooding can be substantially different. Consequently, the growth of Sitka spruce would be much better on an "open" type of landscape.

*The Flood Hazard Classification*

The natural routing of floodwaters into and out of a mainland or island floodplain can often be identified on aerial photographs. This observation formed the basis of the classification system. The process of classification begins with the identification, on 1:10,000 aerial photographs, of topographical and morphological features (described below) that affect flood height and duration. The classification ranges from class I, where flooding does not affect spruce growth to class V, where establishment and growth of spruce is impossible. This classification was designed for use as an inexpensive first step in stratifying the areas designated as favourable for stand rehabilitation work. Field surveys often cannot identify the geomorphic features that serve as routes of entry and exit of flood waters because of the dense brush and the small elevational changes involved. It is necessary to get an overall view of the floodplain island because the classification system is based on the processes of flooding and the identification of floodwater routing. This overall view can only be achieved by using aerial photography.

The objective is to use the system to stratify areas for silvicultural prescriptions, prior to commencing rehabilitation work. Areas identified as high flood hazard would be avoided or planted with more flood-tolerant species such as cottonwood.

The main features used to map the classes on the photos are:

1) **Linear depressions that are "open" to the main channel:** These are usually old abandoned backchannels. Because of their elevation and "open" nature they are frequently inundated and remain so for relatively long periods of time. These characteristics prevent the establishment and growth of Sitka spruce and thus are classed as V. A second important consequence of the presence of the "open" depression is their role as a route of entry of river water onto the floodplain, when the river is below full bank flow. These depressions are easily identifiable on the aerial photos and, by following them up into the floodplain, point to areas that will be flooded before full bank flow occurs.

2) **Depressions that are "closed" to the main channel:** These features don't flood as early as the "open" type depressions, but because they are "closed", once they are flooded the floodwater becomes trapped and the water ponds. Vertical infiltration of the ponded water is slow, occurring only at the rate of the fall of the water table.

3) **Ridges, hummocks and elevated areas:** Although these areas may be submerged a few times a year, the duration of flooding is very short (a few hours). After mapping areas targeted for rehabilitation with this system field reconnaissance can confirm the classification using vegetation indicators.

The definition of the 5 classes are as follows:

**Class V**

| | |
|---|---|
| Frequency - | Floods at a wide range of flows, several times a year for extended periods |
| Duration - | Several long duration flooding episodes each year. Total number of flooded days a year can exceed 30-40. |
| Implications - | No hope for Sitka spruce seedlings. Should be classed as non-commercial (NCC). |
| Geomorphology Topography - | Located in the lowest elevations at the bottom of "closed" or "open" depressions. |

## Class IV

| | |
|---|---|
| Frequency - | Floods several times a year with mean annual high flows. |
| Duration - | Flooding occurs usually twice or three times a year for a total of 20-25 days - longer for higher peak flows. |
| Implications - | Growth rates of spruce seedlings is reduced, establishment is often not successful, cottonwood may be preferred. |
| Geomorphology Topography - | Located immediately above class V or in moderate depressions that are "closed" to free drainage. Although these sites are at the same elevation as class III, the "closed" characteristic increases duration of flooding and consequently affects growth and establishment of planted seedlings. |

## Class III

| | |
|---|---|
| Frequency - | Floods several times a year with mean annual high flows. |
| Duration - | Flooding usually occurs twice or three times per year for a total of 10-15 days - longer for higher peak flows. Note the shorter duration differentiates it with class IV. |
| Implications - | Growth of Sitka spruce is less than ideal, but can be acceptable. Survival can vary, depending on extent of flooding the year the seedlings are planted. |
| Geomorphology Topography - | Same elevation as IV but sites are not confined - The most important characteristic is the "open" configuration. |

## Class II

| | |
|---|---|
| Frequency - | Floods annually, usually once in the spring and once in the fall to a depth of 30-90 cm. |
| Duration - | Short - several hours to 1-2 days. |
| Implications - | Growth is not optimum, but is good. |
| Geomorphology Topography - | High ground located between Class III and I. On aerial photos it is difficult to distinguish between I and II, however because both are safe classes, this has little consequence. |

## Class I

| | |
|---|---|
| Frequency - | Flooded not more than once a year. |
| Duration - | If flooded at all, duration is short - a few hours to half a day. |
| Implications - | The short duration flooding has no detrimental effect to tree growth. |
| Geomorphology Topography - | High ground |

I applied the classification to the tree height-ground elevation data collected on Island 002. I grouped the 125 observations into the 5 classes (Fig. 5). The data fit well into the classes. In class I, where growth is the best, seedling height becomes independent of ground elevation because growth has reached a maximum. In class II, no obvious relationship exists between seedling height and ground elevation. These trees are on relatively high sites where flooding has little effect. Their growth depends more on factors other than flooding. The trees in class III and IV are located within the same elevation. However trees in class III are taller because they are located in "open" better drained landforms. Better drainage implies less time submerged and consequently better growth. In class V, the planted trees did not survive.

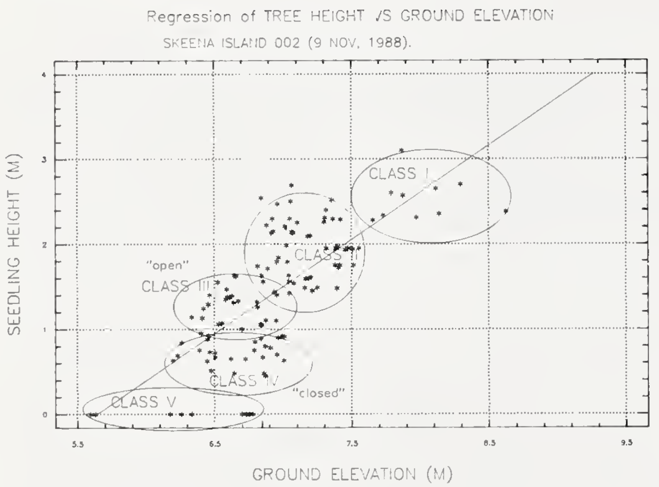


**Figure 5. Flood hazard classification applied to field data.**

The system requires further refining. We have begun work in correlating successional vegetation and soil types with the flood hazard classification, but because it is only in its initial stages it cannot be reported here. However, silviculturists already see it as a useful tool for initial planning on floodplains of large coastal river systems.


## Acknowledgments

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# Simulating Vegetation-Water Yield Relations in Interior Alaska

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***Abstract.*** Spring runoff in cold climates is affected by the complex interaction of snowmelt rate and soil infiltration capacity. The former is affected by all factors influencing the snowpack energy balance, while the latter is affected by soil texture and the combination of autumn soil moisture, snowpack depth and air temperature that determines soil freezing and thawing. These complex relationships are also influenced by vegetative cover. Accordingly, a hypothesis has been made that runoff will increase after timber harvest, not only due to increased snowmelt rates and decreased transpiration, but also due to increased fall soil moisture and subsequent formation of concrete frost. Since no vegetation-water yield field experiments have been done in interior Alaska, a watershed model designed to study vegetation-water yield relations was modified to include a soil freeze-thaw algorithm (Stefan-St.Paul equations) and used to simulate the interaction of forest cover, soil moisture, soil frost, infiltration, and spring runoff. Simulation results support the hypothesis outlined above but also indicate the conditional nature of the vegetation-water yield connection. Simulations also indicate that the drier the initial soil conditions, the longer may be the delay in runoff response to harvest.The model does appear to realistically simulate the great variability in spring runoff patterns observed in interior Alaska and provides direction for further research. These results, as well as the general approach, should be useful to watershed managers in explaining the variability of spring runoff events and in estimating potential impacts of vegetation changes on water yield.

The role of forests in controlling streamflow, hypothesized for decades, has been confirmed experimentally in many locations and that knowledge configured and organized into a variety of mathematical models (Swift et al., 1975; Fox,1976; Waring et al., 1981). The experimental watershed studies and subsequent sensitivity analyses with these water balance models, have allowed some order to emerge from the complex of vegetation-water relations. Thus, for some areas of the country scientist can tell the manager something more specific than the traditional " it all depends."

In interior Alaska, as well as in the northern forested areas, seasonally frozen soils can be a potentially significant factor that has not been explicitly considered in today's generation of vegetation-water yield models (Waring et al., 1981;Bernier, 1985). Although no direct forest manipulation-runoff studies have been performed in interior Alaska, other field studies and observations have led to a hypothesis that runoff will increase during the first year after forest harvest. As in other regions, these increases would be due to increased snowmelt rates and decreased evapotranspiration. However, an even greater increase is hypothesized for the second year after cut, in response to high pre-freeze soil moisture contents. The latter sets up conditions for "concrete frost" formation, reduced infiltration of spring meltwater and subsequent increased overland flow (Fox, 1979). Unfortunately, the extreme variability of spring runoff in the boreal forest and its sensitivity to variations in pre-winter soil moisture contents, even under fully vegetated conditions, make designing a field experiment to test this hypothesis, very difficult. In this paper, an attempt is made to investigate this hypothesis with the aid of a water balance model that includes the freezing and thawing of soils.

## Related Work

Although no direct timber harvest-water yield studies have been done in interior Alaska, their have been some important and relevant studies. Certainly the relationship between vegetation and permafrost has been well documented (Benninghoff, 1952; Brown, 1965; Kallio and Rieger, 1969; Viereck, 1965, 1970, 1973; Dyrness, 1982; Dyrness et.al., 1988). However, much of the commercial timber in interior Alaska is on south-facing, permafrost-free sites. Ironically, little well documented information exists on frost depths and soil moisture contents in these stands. Lotspeich (1973) measured frost and thaw depths for three years under undisturbed forest conditions, but no forest cutting or comparisons to unforested plots were made. Again, the variability due to winter temperatures and snow depths were noted. Kane et.al. (1978) showed that snowmelt infiltration into frozen but dry soils results in little runoff. In latter studies Kane (1980) and Kane and Stein (1984) showed the importance of the fall soil moisture contents in generating spring overland runoff in interior Alaska. Several other studies indicate that fall soil moisture level is an important regulator of spring runoff in northern regions (Augustine,1941; Trimble et.al., 1958; Willis et.al., 1961; Stoeckeler and Weitzman, 1960; Harrold and Roberts, 1960; Baker, 1972; Harris, 1972; and Engelmark, 1984). Yet, few efforts have been made to incorporate frozen soils explicitly into watershed models. Gray et.al.(1985)

represented infiltration into frozen Praire soils in the U.S. Weather Service Sacramento model, by setting infiltration rates as a function of surface soil moisture contents and snowpack water equivalent just prior to snowmelt. They did report improved hydrograph fitting using their infiltration model yet did not actually simulate frost depths and thaw depths. Sand and Kane (1986) modified the Swedish HBV-3 model via seasonal adjustments to soil parameters in an attempt to reproduce hydrographs from the Chena river near Fairbanks. Again, there was no physically meaningful attempt to incorporate soil freezing and thawing. Recently I discovered a paper by Bel'chikov and Koren' (1979) that does explicitly incorporate the soil freeze-thaw process into a water balance model. Although the specific equations and functions they used are different than those I have employed, their approach and mine are conceptually similar.

## Methods

*The Watershed Model*

The watershed model used as the framework for incorporating freeze-thaw calculations is called HYFOR and is described fully in Fox (1976). Briefly, the model is one designed to conceptually accommodate the variable-source-area theory of streamflow production and specifically to investigate vegetation-water yield relationships on a monthly, seasonal, or annual time scale. Daily water budget accounting is performed on elevation zones of watershed segments (Fig. 1). A segment is defined as a sequence of adjacent elevation zones running from a stream link or point to the topographic divide. Depending on the watershed size and the degree of subdivision desired, a segment can be defined as a whole watershed, a subwatershed or interfluve of the main channel, or as a hillslope transect originating along a channel reach and extending upslope, normal to the contour, to the watershed divide. The uppermost elevation zone of a segment receives input only from precipitation/snowmelt with all sequentially lower elevation zones also receiving lateral surface and subsurface input from the adjacent higher zone. The elevation-zone surface and subsurface flow is partitioned between streamflow and flow to the next lower elevation zone as a function of the topography; ie., that percentage of the elevation zone draining directly to a channel. The vertical structure of a typical elevation zone consists of two canopy strata and four soil zones or compartments. The daily outflow or drainage of one

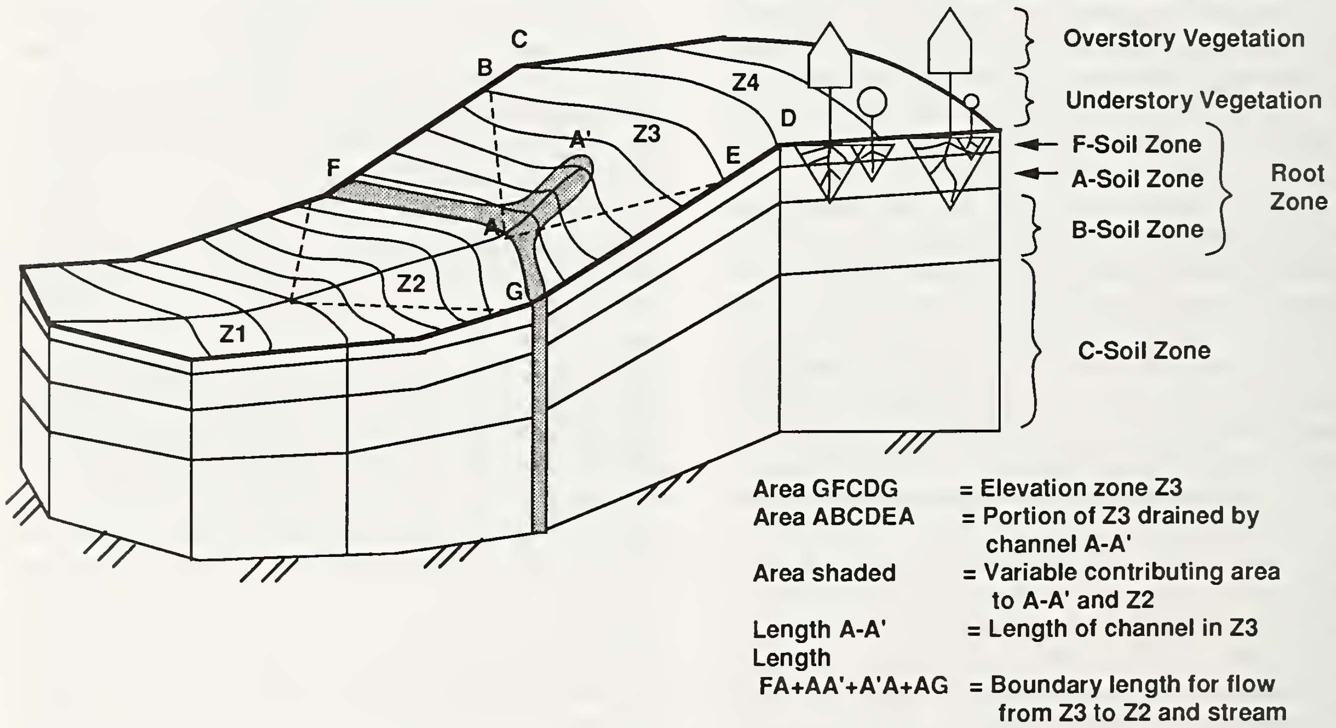


**Figure 1. Model representation of a watershed segment with four elevation zones, two canopy strata, and four soil compartments.**

compartment is calculated as a percentage of that compartment's water content and becomes the vertical input to the next lower compartment. Lateral outflow from a compartment is allowed only if discontinuities in soil hydraulic properties exist between compartments and is calculated as a function of the compartment's water content, slope steepness and the ratio of elevation zone contributing area to the total elevation zone area. Contributing area is calculated for each soil compartment of each elevation zone, as the product of hydraulic conductivity and elevation zone lower boundary length (the latter estimated as the length of the contour separating the two elevation zones plus twice the length of channels within the elevation zone). No vertical drainage is allowed for the deepest soil compartment. All subsurface outflow from this compartment is lateral and downslope to a channel or to the same soil compartment of the next elevation zone. Each soil compartment is characterized by a soil textural classification, compartment thickness, and initial volumetric moisture content. Detailed hydraulic/hydrologic and thermal properties are then internally assigned based upon soil texture. Infiltration in the model is controlled by the daily rate of delivery of water to the soil surface and the available storage capacity in the soil profile. No "infiltration rate" or "capacity rate" is modeled since only daily precipitation and temperature data are used. This implies that all water delivered to the surface in a day can enter the soil if there is pore space available in the surface soil compartment. Overland flow can also occur in the model via "exfiltration" as water enters a lower elevation zone soil compartment as both vertical inflow (rainfall/snowmelt/vertical drainage), and as lateral inflow from the upslope elevation zone. If these inflows exceed that soil compartment's porosity the excess is added to the soil compartment above it successively until no further excess exists or until the surface is reached and the excess becomes overland flow. As will be discussed below, the freezing of soils at a high moisture content inhibits internal drainage and reduces the available porosity for snowmelt or spring rainfall infiltration.

*Freeze-Thaw Equations*

The simple Stefan equation has been used for years by engineers to estimate frost penetration and thaw depths in soils and other media as a function of the cumulative, surface freezing or thawing index and the thermal properties of the medium (Stefan, 1890 as cited by Jumukis,1977). Assuming sensible heat effects are negligible, frost depth is given by

$$D_{fr} = [48 \cdot K_{fr} \cdot I_{sur} / (L \cdot \theta)]^{1/2} \tag{1}$$

where

$D_{fr}$ = Depth of frost from surface, cm.

$K_{fr}$ = frozen soil thermal conductivity, cal $cm^{-1}h^{-1}{}^{o}C^{-1}$

48 = 2. x 24 h/day

$I_{sur}$ = surface freezing index, cumulative degree-days, $^{o}C$

= $n_{fr} \cdot I_{air}$

$I_{air}$ = air freezing index, cumulative degree-days, $^{o}C$

$n_{fr}$ = ratio of surface freezing index to air freezing index

L = latent heat of fusion, cal/g

$\theta$ = volumetric moisture content, $g/cm^3$

Kersten (1959) developed a procedure, commonly referred to as the St. Paul (Minnesota) equations, to apply the Stefan equation to layered media. Details on the derivation of this method can also be found in Jumukis (1977) and in Lunardini (1981). In summary, frost depth (thaw depth) is calculated by comparing the number of freezing degree-days needed to freeze each successively deeper soil layer, with the number of available freezing degree-days. Accordingly, if there are enough freezing degree-days available to freeze the uppermost layer, it is considered frozen, the number of freezing degree-days available to the next layer is reduced, and the thermal resistance is increased based upon the thermal conductivity and thickness of the just frozen layer. The number of freezing degree-days necessary to freeze the next layer is then calculated, compared to the remaining available freezing degree-days, and either part or all of the layer is frozen. This progression through the layers is continued until all available freezing degree-days are used up. In mathematical notation the degree-days necessary to freeze the top soil compartment is

$$N_1 = (L \cdot \theta_1 \cdot x_1 \cdot R_1) / 48. \tag{2}$$

and for the nth compartment

$$N_n = [L \cdot \theta_n \cdot x_n / 24.] \cdot [\sum_{i=1}^{n-1} (R_i) + R_n/2] \tag{3}$$

where

$N_n$ = number of degree-days necessary to freeze nth compartment

$x_n$ = thickness of the nth soil compartment, cm.

$R_n = x_n/K_n$ = thermal resistance of nth compartment, h $cm^2$ $^oC$ $cal^{-1}$

$\sum_{i=1}^{n-1}(R_i)$=cumulative thermal resistance of the profile above the nth compartment, h $cm^2$ $^oC$ $cal^{-1}$

$N_{(n+1)}$ is the number of unexpended freezing degree-days available after completely freezing n compartments. The depth of frost penetration into the (n+1) compartment is given by

$$d_{(n+1)} = -K_{(n+1)} \cdot [\sum_{i=1}^{n} R_i] + \{K_{(n+1)}^2 \cdot [\sum R_i]^2 + 48 \cdot K_{(n+1)} \cdot N_{(n+1)}/(L \cdot \theta_{(n+1)})\}^{1/2} \quad (4)$$

and the total frost depth is the sum of the completely frozen compartments plus the frost penetration into the partially frozen (n+1) compartment or

$$D_{fr} = \sum_{i=1}^{n} (x_i) + d_{(n+1)} \quad (5)$$

Usually, these calculations are performed using average seasonal values of soil thermal conductivity and a climatological average or design value for the air freezing index multiplied by an empirical or literature-derived, surface n-factor. Thaw penetration is calculated in a similar manner using cumulative thawing degree-days (thaw index) and unfrozen soil thermal conductivity.

A similar procedure known as the "modified Berggren equation" is commonly used but requires the determination of another parameter, l, to account for sensible heat effects (Aldrich and Paynter, 1953). Unlike the St. Paul equations, the modified Berggren method requires the error function and an iterative procedure for solution. For simplicity, therefore, the St. Paul equations were used in this study.

The general features of HYFOR, as well as other water balance models, are conductive to incorporating the St. Paul equations in a straightforward manner because of the layered subsurface structure of an elevation zone. The major change in performing the freeze-thaw calculations within the water balance model is to implement them on a daily rather than seasonal basis. This allows for the daily updating of each compartment's soil moisture as well as the daily accumulation, densification, and ablation of snow on the surface. This, in turn, allows for a daily updating of soil/snow thermal conductivity, latent heat of fusion ($L\theta$), and profile thermal resistance. Although such coupling seems rather simple, there are several secondary considerations which tend to complicate the problem.

*Snow*

Frost penetration is extremely sensitive to snowpack depth and density, particularly in conjunction with the timing of snowfall versus cold spells throughout the winter. A major implication for the water balance is that no longer is snowpack accounting on a water equivalent basis sufficient. Rather, there must now be a snowpack depth and density accounting scheme as well. If the thermal conductivity of snow is represented as a function of snow density, then snowpack thermal resistance can be calculated daily as depth/thermal conductivity. The snowpack can now be considered as another layer in the St. Paul equations. Since the snowpack layer is, of course, already frozen, its major impact will be to increase the cumulative thermal resistance to frost penetration into the soil profile. This approach eliminates the need to model specific temperatures at the base of the snowpack since the surface freezing degree-days are now calculated at the snow surface. It is assumed that no significant soil thawing takes place until the snowpack has melted and surface temperatures are above freezing.

*Surface Degree-Days (n-factor)*

HYFOR uses only maximum-minimum air temperatures as input data from readily available U.S. Weather Service screenheight records (usually 1.5-2 meter height). However, almost all degree-day methods of freeze-thaw determination utilize similar data (usually degree-day indices are calculated separately for the freezing and thawing seasons on a cumulative basis) modified by an empirical or literature cited value of the surface n-factor, relating surface degree-day index to screen height values for a given surface type. Lunardini (1978) reviews several studies of n-factors and details a theoretical treatment which invokes surface energy balance determinations. A relatively simple, yet conceptually rational representation of surface n-factor dynamics is needed to realistically link the freeze-thaw calculation with surface manipulations such as timber harvest, fire, etc. Qualitatively, one might assume that surface temperature would increase above screen height air temperature as the incident radiation increased, and as the surface albedo, wind speeds and soil moisture decreased. After extensive review of different approaches to estimating surface-n factors I decided to use a combination of energy balance and aerodynamic approaches to calculating heat transfer between the ground surface and the air. This results in a relationship whereby surface temperature is calculated as air temperature plus or minus an increment determined as a function of isothermal net radiation (which may be positive or negative), water content of the soil surface, wind speed and surface roughness. When snow covers the ground, snow surface temperature is considered equal to air temperature as long as air temperature is less than or equal to 0°C.

*Experiments*

A hypothetical set of data was used to describe a small watershed of one segment and one elevation zone having a south facing, 20 % slope, and 15 cm organic layer over a deep silt loam soil. The October 1979 to September 1980 daily climatological data from the Fairbanks airport weather station was used as an input data set to the model. This data set represents a relatively low snowfall and mild winter. The October through March precipitation was later increased by a factor of 2.5 to test the effects of a deep snowpack on vegetation-runoff relations. Initial moisture contents of the soil were set such that the system would be in annual balance. Then a two year control run (with identical daily input for both years) was simulated. Next, a two year run in which all vegetation was removed was simulated. The same analysis was repeated for the "deep snowpack" conditions. In addition, a sequence of six successive years of "deep snowpack" winters following a very dry initial soil profile, was simulated under conditions of no vegetation, to explore the possibility of a response delay beyond two years.

## Results and Discussion

Simulation results for the shallow snowpack conditions are shown in Table 1 and Figures 2, 3 and 4 while results for the deep snowpack conditions are shown in Table 2 and Figures 5, 6 and 7. For the shallow snowpack case, there was little runoff at all from the control and although the relative increase due to vegetation removal was large, the absolute runoff values were still small. However, the annual change in storage increased dramatically in the clearcut case by the end of the first year. During the second year following harvest (assuming no regrowth) there is an approximate 16 fold increase in runoff when compared to the control. The fact that there is still a net gain in storage at the year's end,

**Table 1. Simulated annual water balance for two sequential, low snowfall water years under control and clearcut treatments.**

| | First Year | | Second Year | |
|---|---|---|---|---|
| | Control cm | Clearcut cm | Control cm | Clearcut cm |
| Total Precipitation | 22.7 | 22.7 | 22.7 | 22.7 |
| Rain | 16.3 | 16.3 | 16.3 | 16.3 |
| Snow | 6.4 | 6.4 | 6.4 | 6.4 |
| Potential ET | 35.7 | 51.1 | 35.7 | 51.9 |
| Actual ET | 21.8 | 4.0 | 21.8 | 5.4 |
| Transpiration | 16.1 | 0.0 | 16.1 | 0.0 |
| Interception | 5.7 | 0.0 | 5.7 | 0.0 |
| Soil Evaporation | 0.0 | 4.0 | 0.0 | 5.4 |
| Total Runoff | 0.9 | 1.4 | 0.9 | 16.1 |
| Overland Flow | 0.0 | 0.2 | 0.0 | 12.7 |
| Sub-surface Flow | 0.9 | 1.2 | 0.9 | 3.4 |
| Change in Storage | -0.1 | 17.3 | -0.1 | 1.2 |
| Max. Frost Depth | 80.8 | 82.8 | 80.8 | 66.5 |
| Date: Frost Starts | 18-Oct. | 18-Oct. | 18-Oct. | 18-Oct. |
| Date: Snowmelt Starts | 01-Apr. | 30-Mar. | 01-Apr. | 30-Mar. |
| Date: Snowmelt Ends | 21-Apr. | 04-Apr. | 21-Apr. | 04-Apr. |
| Date: Thaw Complete | 07-Jul. | 21-Jun. | 07-Jul. | 08-Jun. |

implies that runoff may be even higher the third year after harvest. Although frost depths were not notably different during the first post-harvest year when compared to the control, snowmelt started earlier and took approximately one-quarter of the time to complete as did the control. In addition, frost was gone from the clearcut soil 16 days before the control. During the second post-harvest year, soil frost only penetrated 66.5 cm as compared to 80.8 cm for the control. This is explained by the high latent heat of fusion for this now very wet soil.

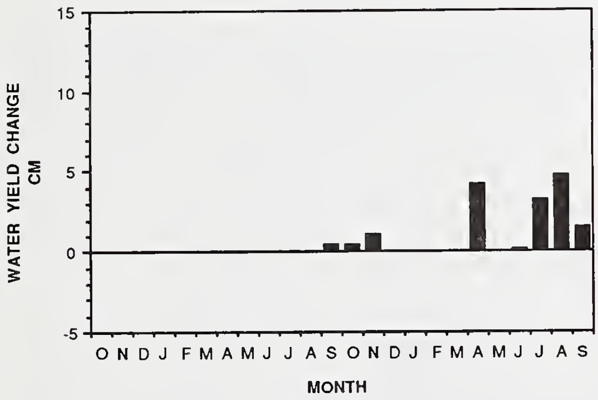


**Figure 2. Simulated change in monthly water yield for two years after clearcut treatment under shallow snowpack conditions.**

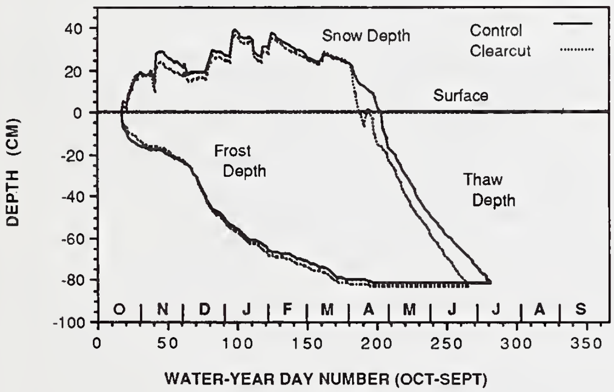


**Figure 3. Simulated snow, frost, and thaw depths for the first year under shallow snowpack conditions.**

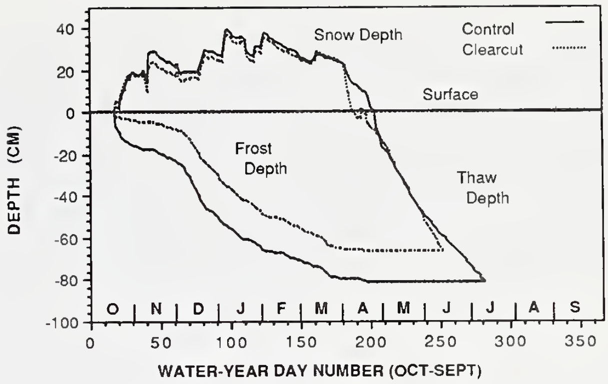


**Figure 4. Simulated snow, frost, and thaw depths for the second year under shallow snowpack conditions.**

Results for the control case under deep snowpack conditions indicate that overland flow can occur in the uncut forest. In fact, for the uncut, deep snowpack case, total runoff was greater than that for the first post-harvest year under the shallow snowpack conditions. Also, frost penetration was only 48.5 cm as compared to 80.8 cm for the control with shallow snow, demonstrating the insulating effect of deep snow. The first year clearcut conditions show an elimination of transpiration and interception losses and an attendant increase in overland flow and year end storage in the soil profile. Frost depth is not too different than under control conditions. Second year runoff under the clearcut treatment was nearly 30 cm with no change in storage and with frost penetration much less than the control. Sartz (1973), working in southwestern Wisconsin, also reported shallower frost depths on plots where woody vegetation was removed than on control plots. In spite of the later dates for completion of snowmelt under the deep versus shallow snow conditions, complete thaw occurred earlier. The major reason for the rapid soil thawing is that the organic layer offers less thermal resistance under these wet conditions than when well

drained. Now, one might expect the organic layer to be wet after snowmelt under both shallow and deep snowpack conditions. However, in the latter case, internal drainage is limiting and infiltrating water is probably perched in the upper profile, keeping the organic layer wetter for a longer duration. Also, one might assume that the profile with higher moisture contents would take longer to thaw due to the high latent heat requirement. This is generally true. However, in the situation simulated here, as soon as the organic layer dries out by drainage and evaporation it becomes a good insulator and the rate of thawing in the underlying silt loam slows down. This process has been hypothesized as contributing to the formation of permafrost (Luthin and Guymon, 1974).

**Table 2. Simulated annual water balance for two sequential, high snowfall water years under control and clearcut treatments.**

| | ---------First Year--------- | | -------Second Year------- | |
|---|---|---|---|---|
| | Control cm | Clearcut cm | Control cm | Clearcut cm |
| Total Precipitation | 33.8 | 33.8 | 33.8 | 33.8 |
| Rain | 18.5 | 18.5 | 18.5 | 18.5 |
| Snow | 15.3 | 15.3 | 15.3 | 15.3 |
| Potential ET | 35.8 | 48.6 | 35.8 | 48.6 |
| Actual ET | 31.3 | 2.8 | 31.3 | 4.0 |
| Transpiration | 25.7 | 0.0 | 25.7 | 0.0 |
| Interception | 5.6 | 0.0 | 5.6 | 0.0 |
| Soil Evaporation | 0.0 | 2.8 | 0.0 | 4.0 |
| Total Runoff | 2.5 | 15.3 | 2.5 | 29.8 |
| Overland Flow | 1.3 | 12.3 | 1.3 | 25.8 |
| Sub-surface Flow | 1.2 | 3.0 | 1.2 | 4.0 |
| Change in Storage | 0.0 | 15.7 | 0.0 | 0.0 |
| Max. Frost Depth | 48.5 | 46.7 | 48.5 | 25.1 |
| Date: Frost Starts | 18-Oct. | 18-Oct. | 18-Oct. | 18-Oct. |
| Date: Snowmelt Starts | 01-Apr. | 01-Apr. | 01-Apr. | 01-Apr. |
| Date: Snowmelt Ends | 01-May | 25-Apr. | 01-May | 25-Apr. |
| Date: Thaw Complete | 23-May | 17-May | 23-May | 09-May |

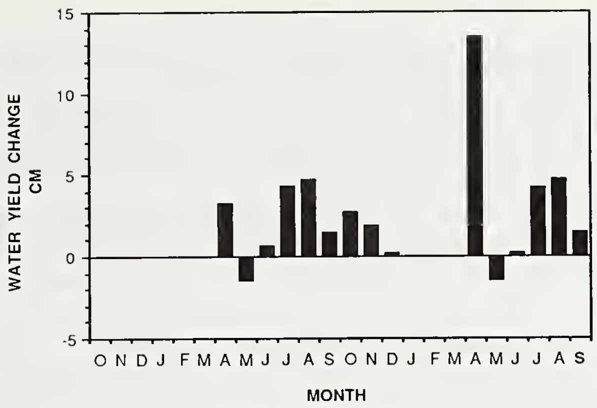


**Figure 5. Simulated change in monthly water yield for two years after clearcut treatment under deep snowpack conditions.**

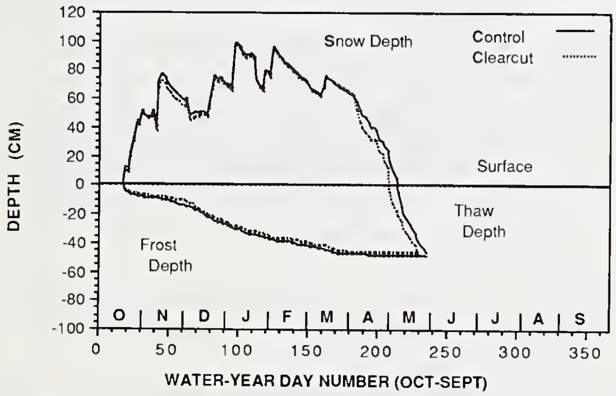


**Figure 6. Simulated snow, frost, and thaw depths for the first year under deep snowpack conditions.**

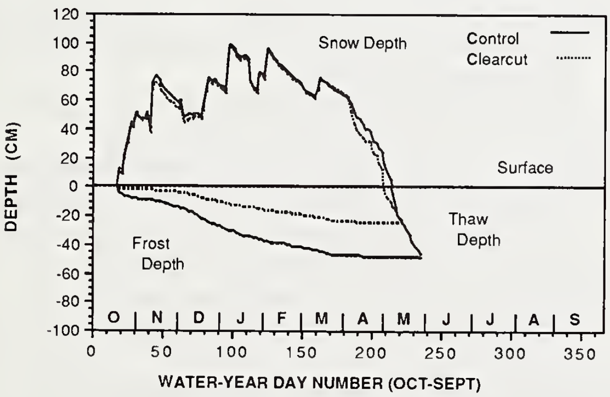


**Figure 7. Simulated snow, frost, and thaw depths for the second year under deep snowpack conditions.**

It is of interest to note that at the end of the second post-harvest year under deep snow conditions, there is no change in storage. This means that if we repeated another year of identical input there would be results identical to those of the second year post-harvest case. There appears to be a relationship between initial moisture conditions of the simulation and the year when post-harvest runoff will be greatest. The results of simulating a deep snowpack year with a particularly low initial soil moisture content reveals a progressive filling of storage capacity until six years after harvest when a large runoff response is observed and equilibrium conditions are reached (ie., no change in annual storage) (Fig. 8). This result is partially due to the low internal drainage rate of the silt loam profile.

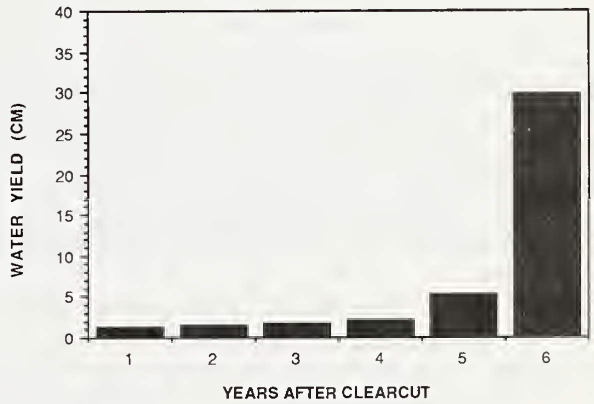


**Figure 8. Simulated annual runoff response to clearcutting on an initially dry soil followed by six meteorologically identical years with deep snowpacks.**

## Summary and Conclusions

The St. Paul equations for calculating freeze-thaw depths in layered media have been coupled with a daily water balance accounting model to investigate the effects of timber harvest on water yield in the boreal forest. Results reinforce the hypothesis that significant increases in overland flow may occur during the second year after harvest and that results are sensitive to the initial condition of soil moisture and to the precipitation during the post-harvest years. The results also indicate that the drier the initial soil conditions, the longer the delay in runoff response to harvest.

Although these results are conditioned by the specific circumstances simulated, the model does allow the sensitivity of the results to those conditions, to be studied systematically. The model also serves as a framework for improving our knowledge of the system by

indicating where additional fieldwork would be most rewarding. Preliminary analyses indicate we still need better field verification of transpiration estimates; a firmer experimental foundation for the relationships among snow depth, density and thermal conductivity; a reliable relationship between screen-height air temperature and surface temperature and between ambient wind speed in the open and wind speed under canopies of different densities. Models such as the one used in this study have the potential of allowing watershed managers to link land and channel descriptive indices to hydrologic processes. With researchers and managers working together management guidelines and prescriptions can be developed that are responsive to local conditions and lead to improved stewardship.

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# Decaying Logs as Moisture Reservoirs After Drought and Wildfire

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***Abstract.*** Decaying wood on the forest floor retains large reservoirs of moisture and thus provides long-lasting, high-moisture microsites that aid in forest recovery after prolonged drought or fire. Examination of logs after the Galice Complex fires in southwest Oregon revealed considerable root and mycorrhizal activity. Mean log moisture (157%) was 25 times greater than mean soil moisture (6%). After extended drought and wildfire, the moisture stored in logs may expedite forest recovery by providing important refuges for roots and associated mycorrhizal fungi of pioneering vegetation.

Fallen trees, in various stages of decay, form an important component of the forest habitat by providing a storehouse for moisture and nutrients and by furnishing a favorable environment for microorganisms that are critical in the growth of commercially important conifer species (Maser *et al*. 1979, Harvey *et al*. 1981). Woody material has a variety of physical and chemical properties important to biological processes (Larsen *et al*. 1980), and is the primary water and food base for a wide variety of essential organisms.

In addition to contributing to the biological diversity of the ecosystem, fallen logs function as a water reservoir in dry areas. Maser and Trappe (1984) found that water content of logs increases with length of time on the forest floor and with stage of decay. Plant moisture stress is probably the primary cause of mortality of conifer seedlings planted in reforestation sites in southern Oregon and northern California (Hermann 1965; Cleary 1971; Hermann 1977; Hobbs *et al*. 1980). During the late summer, soil moisture is at its lowest level (Amaranthus, unpublished data) due to infrequent summer precipitation, warm temperatures, and the low water-holding capacity of many soils (Meyer and Amaranthus 1979; Johnson and Beschta 1980; Kandiko *et al*.). 1980. Potential for wildfire is greatest during this period and sources of plant-available moisture may be critical for recovery of vegetation.

## Methods

*Site description*

Our study was conducted in an area that had been intensely burned during the Galice complex fires in 1987. The 8-ha site is located on the upper south fork of Galice Creek in the Klamath Mountains of southwest Oregon. The aspect is northeast and the steep slopes average 50 percent. Soils are well drained loam with clay-loam subsoils underlain by amphibole gneiss parent material at a depth of 40 to 90 cm. Surface layers, down to 12.5 cm, are dark reddish-brown and average 45 percent rock fragments. Sand, silt, and clay percentages are 55, 27, and 18, respectively.

The area had been clearcut in 1965, broadcast burned in the fall, 1967, and planted with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the spring of 1969. At the time of the Galice Complex fire, Douglas-fir, white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), and incense-cedar (*Libocedrus decurrens* Torr.) were growing on the site at a density of about 1000 trees/ha. Sadler's oak) *Quercus sadleriana* R. Br. Campst), greenleaf manzanita (*Arctostaphylos patula* Greene), and chinkapin (*Castanopsis chrysophylla* (Dougl.)A. DC.) were also abundant.

The wildfire burned the site with high-burn intensity on 1 September 1987. Surface litter and duff and the crowns of existing vegetation were completely consumed. Some initial sprouting of the brush species was noted on 8 October, just 38 days after the fire. The site averaged 15 down logs per acre, most of which were class II or class III, based on the system devised by Maser *et al*. (1979). These logs were completely charred to a depth of 2.5 to 10.0 cm, reducing the diameter of the majority of them to between 20 and 45 cm.

The area experiences very low summer rainfall. Total precipitation, recorded at the weather station on Onion Mountain, 6.4 km from the study site, was 100 cm from 1 September 1986 to October 1987, with less than 7 percent falling between 1 June and 1 October (Table 1). No precipitation occurred in the 77-day period prior to sampling.

**Table 1. Onion Mountain Precipitation-September 1, 1986 to October 1, 1987.**

| Month | Precipitation | Month | Precipitation |
|---|---|---|---|
| 1986 | cm | 1987 | cm |
| Sept | 9.9 | Jan | 18.9 |
| Oct | 9.7 | Feb | 6.1 |
| Nov | 12.6 | Mar | 21.9 |
| Dec | 8.7 | Apr | 2.3 |
| | | May | 3.0 |
| | | June | 1.0 |
| | | July | 5.8 |
| | | Aug | 0.0 |
| | | Sept | 0.0 |

*Field Procedure and Analysis*

On 9 October 1987 we sampled eight Douglas-fir logs, four from class II and four from class III (Maser *et al*. 1979), using a dot grid to ensure random selection from each class. Two 15 cm (6-inch) sections were cut at random locations along each log. The presence of roots and mycorrhizae was recorded for each sample. Two soil samples, each approximately 300 g, were taken at a 3 to 10-cm depth within 1.5 m of the sample logs.

Wood and soil samples were placed in plastic bags and transferred to the laboratory, where they were weighed and oven dried at 70°C for 30 hours. Wood and soil moisture values were calculated for each sample by substracting wet weight from oven dry weight and dividing by oven-dry weight. Means, variance, and standard errors were computed for paired values of wood and soil moistures and compared by a Student's t-test. Data on moisture for class II and class III logs were also compared.

## Results and Discussion

We found tremendous quantities of water stored in the class II and class III logs. Even after 77 days without rain and an intense fire, we could wring water out of the wood. The logs we sampled contained 25 times more moisture on a weight basis than did soil samples (157% compared with 6%, Table 2). Class III logs held significantly more water than did class II logs (199% compared with 119% Table 3).

Comparing moisture contents on a weight basis between organic material and mineral soil can be misleading since the bulk densities, thus the unit weights are different. What is cited as a 25 x difference may be closer to 10 to 15 x difference if expressed on a volumetric basis. Values expressed on a volumetric basis are difficult to attain because of problems in accurately determining the bulk density of rotten logs. The conclusions of the study would remain unchanged, however, using either method because of the magnitude of the differences between soil and log moistures.

**Table 2. Log and soil moisture content following wildfire.**

| | Moisture (% of Dry Weight) | Standard Error | t-value |
|---|---|---|---|
| Log | 156.7 | 19.0 | 7.66 |
| Soil | 6.1 | .8 | |

In winter, large amounts of water are stored in decaying wood. As the stage of decay advances, the wood becomes more porous and therefore retains more water. The presence of this moisture after drought and fire may help pioneering plants become established where available soil moisture is low.

Most of the woody plants of the Pacific Northwest forests depend upon ectomycorrhizae for water and nutrient uptake. Harvey *et al*. (1979) found large numbers of ectomycorrhizae in organic material with significantly more occurring in decaying wood than in soil. The importance of decaying wood in supporting feeder-root and ectomycorrhizal activity may be much greater on dry sites than on moist sites (Harvey *et al* 1986). The wood component becomes critical when those dry sites are also low in nutrients.

Mycorrhizae were widely distributed in class III logs. Amaranthus *et al*. (1987b) found that the presence of native mycorrhizae is important for seedling growth after clearcutting and intense burning on droughty sites in southwest Oregon. In another study on a droughty southwest Oregon site, nitrogen fixation was associated with ectomycorrhizal activity (Amaranthus *et al* 1987a). In periods of adequate moisture, humus supports the highest level of ectomycorrhizae, but during periods of drought soil wood becomes the most active site (Harvey *et al*. 1982; Larsen *et al*. 1982). Thus, during the dry season, the wood component provides not only essential moisture and nutrients, but also the means of utilizing them.

Protection or enhancement of the organic component of the soil is a primary requisite for maintaining long-term forest growth. In the Klamath Mountains, conifer seedling performance can depend on the ability of soil to retain moisture and support nitrogen-fixing and ectomycorrhizal organisms (Amaranthus and Perry 1987; Amaranthus and Perry 1988). The removal of large amounts of organic material may result in difficulty in the reforestation of these thin, droughty, or infertile soils.

In the managed forest, harvesting, yarding nonmarketable material, broadcast burning, and tractor piling reduce the wood component in the ecosystem. The long and short-term consequences of this reduction are of growing concern to forest managers. A balance between fuel management guidelines and protection of the wood component of forest soil is critical. Large accumulations of woody residue can create a potential for wildfires of increased intensity, which would result in a lack of organic material and thus limit subsequent growth. When forest managers are analyzing for fire risk, they should take into account the high water content of fallen logs during the period in which wildfire potential is greatest. Class III logs in our study had a moisture content of 199%.

**Table 3. Moisture Content for Class II and Class III Logs.**

| | Moisture (% of Dry Weight) | Standard Error | t-value |
|---|---|---|---|
| Class II Logs | 114.0 | 5.5 | 3.98 |
| Class III Logs | 199.5 | 20.7 | |

Fallen trees, in a range of decay classes, therefore provide a long-term reservoir of moisture. A continuous supply of woody material left on the forest floor, not only protects the productive potential of the forest soil, but also provides a sanctuary for ectomycorrhizae and a significant source of moisture in the event of prolonged drought or wildfire.

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# Logging of Temperate Rainforests and the Greenhouse Effect: Ecological Factors to Consider

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***Abstract.*** This is a review of the carbon budget and the principal ecological processes regulating carbon flow in forest ecosystems and includes preliminary data on carbon cycling in temperate rainforest regions. Old-growth forests in Southeast Alaska were estimated to accumulate 150-300 t C/ha on average to productive sites. Second growth sites were estimated to accumulate 131-227 t C/ha at 110 years of age on average sites. The highest biomass accumulations generally occur at 200-300 years of age. Logs were estimated to contain 20-40 t C/ha in old-growth sites. Southern hemisphere sites had similar carbon storage in second growth hardwood sites, but had as much as 3 times greater storage in old-growth conifer types. Little information is available on how much soil and forest floor carbon is lost following logging in the temperate rainforest zone.

In temperate forests studied to date deforestation and subsequent management has resulted in a net emission of carbon to the atmosphere due to lower equilibrium carbon pools (in trees and soil) and a more rapid turnover of carbon. Disposition of forest products is a key variable in determining the net effect of forest management activities on atmospheric carbon. Because of the small land area involved and the high degree of reforestation following logging, effects of land use practices in the temperate rainforest zone are expected to have little effect on global atmospheric carbon. Basic research on decomposition, microclimate and soils changes with logging are needed to better understand the productivity potential of the full range of temperate rainforest sites and to more precisely predict what impact land-use practices may have on atmospheric carbon.

The prospect of global climatic warming caused by a buildup of carbon dioxide and other pollutants in the upper atmosphere has helped focus much scientific and media attention on how man's actions can modify global climate, and on the importance of understanding the basic ecological processes that govern forest ecosystems. Although most researchers consider the burning of fossil fuels to be the primary cause of the "greenhouse effect" (whereby the earths reradiation of heat to outer space is more efficiently captured by atmospheric gases such as carbon dioxide ($CO_2$) or methane ($CH_4$) to cause global warming), much recent debate has focused on how the growth and clearing of rainforests affects atmospheric carbon (e.g. Armentano and Ralston 1980, Goudriaan and Ketner 1984, Henderson-Sellers and Gornitz 1988, Hobbie et al. 1984, Houghton et al. 1987).

Most investigators have concluded that ongoing deforestation of tropical rainforest regions has led to increased emission of atmospheric carbon of up to 2.5 x $10^9$ t C/yr (Armentano and Ralston 1980, Delcourt and Harris 1980, Kobak and Kondrasheva 1985, Houghton et al. 1987, Emanuel et al. 1984, Goudriaan and Ketner 1984). Temperate forests are considered a small carbon sink (0-1.2 x $10^9$ t C/yr) due to forest regrowth and afforestation following two centuries of massive deforestation . For example, since 1860 approximately 165 and 150 x $10^9$ t C have been emitted to the atmosphere from the burning of fossil fuels and deforestation respectfully (Moore et al. 1987). It is generally assumed that changes in albedo (reflection of solar radiation on the ground or on top of plant canopies) have had little effect on climatic change but there is still insufficient information to assess the complete microclimatic implications of widespread forest clearing (e.g. Henderson-Sellers and Gornitz 1988).

Debate over the relation between forest clearing in the temperate zone, and atmospheric carbon has recently centered on the ability of managed young-growth forests and old- growth forests to sequester atmospheric carbon. In a recent study, for example, the prospect of decreasing $CO_2$ through intensive forest management and global afforestation was investigated (DOE 1988). It was concluded that to sequester 5 x $10^9$ t C/yr (the estimated annual emission of $CO_2$ from fossil fuels in 1980) the net annual productivity of the worlds closed forests would have to be doubled (or trees planted over an area equivalent to the total area deforested in the world to date), deforestation halted, and forest products prevented from burning or decay. Observations that trees in managed forests grow much faster than trees in old- growth forests has led to recent claims that conversion of existing old-growth forests to managed second-growth forests could led to increased sequestering of atmospheric carbon (e.g. Glasborro 1989). Temperate rainforests have been the focus of this debate since they have a higher proportion of existing old-growth than most other temperate forest types.

For purposes of this paper temperate rainforests are defined to include forests in cool climates with heavy

rainfall year around. Specifically they include forests with a mean July isotherm < 16°C, annual rainfall > 1400mm and distributed throughout the year, fire not a common natural occurence, and with a dormant season caused by short days and/or low temperatures. The two largest forest regions meeting this definition include the southern coast of Chile and the northern Pacific coast of North America.

In this paper I 1) review ecological literature relating to the carbon dynamics of old-growth and young growth forests and 2) make a preliminary evaluation of both the short-term and long-term effects of converting old- growth temperate rainforests to young-growth forest on atmospheric carbon.

## Methods

Forest mensurational data were collected on permanent plots located in old-growth forests on average to productive sites (Taylor 1934) throughout Southeast Alaska, and in two sites in southern Chile. In each site a 0.25 - 0.5 ha slope-corrected plot was established. The diameter of all trees > 5cm in diameter at breast height were measured, and a representative subsample were measured for height and age. In most locations trees were mapped and tagged for future remeasurement. In addition the volume and decay class of all logs > 10 cm in diameter and 3m in length were measured within the plot. Stand tables from Taylor (1934) were used to characterize the structure of highly productive and unproductive second-growth stands at maturity in Southeast Alaska (110 and 150 years of age). Literature values were used for determining carbon storage by temperate rainforests in other localities. In regions where no published biomass values exist, approximate conversions from timber volume inventories were used (Johnson and Sharpe 1983).

Carbon storages in forests of Southeast Alaska were calculated by using individual tree biomass equations developed for ***Tsuga heterophylla*** in Oregon (Gholz et al. 1979) and for ***Picea sitchensis*** in coastal Alaska by Bormann (1989). Because sapwood was not measured, and site specific equations for estimating foliar biomass were not made, estimates of foliage and branch biomass were subject to more error than the woody biomass estimates, but were still judged adequate for purposes of general comparisons (see Bormann 1989). Down log biomass was computed using volume equations and bulk density samples stratified by log decay class (Sidle and Alaback, unpublished data, cf. Means et al. 1985). Carbon was assumed to comprise 50% of the biomass.

To study decomposition patterns, filter papers were buried in the litter layer of 150 plots in each of two 3-yr old clearcuts in northern Southeast Alaska. Approximately half were placed in slash burn areas and half in controls. Papers were collected 1 yr after plot establishment, manually cleaned and weighed. Instantaneous litter and soil temperatures were taken early in the morning and throughout the day while collecting the filter papers. Continuous monitoring of air, litter, and soil temperatures with a datalogging system in an old-growth site at the same elevation was used for comparison.

## Results

*The Carbon Budget*

Before any analysis can be made of the effects of forest management activities on atmospheric carbon it is first necessary to understand the carbon budget of an old-growth forest ecosystem. To understand the carbon budget is to understand the complete production budget of a forest ecosystem (Fig 1). Much confusion over the nature of forest productivity arises from different definitions of the term. For most ecological studies productivity is defined as follows:

$$NPP = B + L + M \tag{1}$$

Where NPP is net primary productivity, B is the annual increment in standing biomass (e.g. tree and understory growth), L is litterfall (annual deposition of leaves, branches, twigs of all plants to the forest floor), and M is tree mortality.

Although it is often assumed that biomass increment, or tree growth is the principal component of forest productivity, the production budget of many ecosystems is dominanted by detrital dynamics, e.g. the mortality and litterfall components. It is often stated that second- growth forests are more productive than old-growth. But in most cases in which comparable sites have been studied the productivities of mature second-growth (50-150 years depending on the site) and old-growth have been similar, although less merchantable wood is produced by old-growth forests (Grier et al. 1981, Franklin and Waring 1980, Ovington 1962). Theoretically, mature forests should sustain a similar rate of production over time (and maintain near maximum leaf area potential for the site), but in practice mortality tends to be episodic, so that ecosystem productivity (and leaf area) is often below its potential.

Unfortunately, little has been published on the carbon budget of temperate rainforest ecosystems so a general characterization of the processes involved has

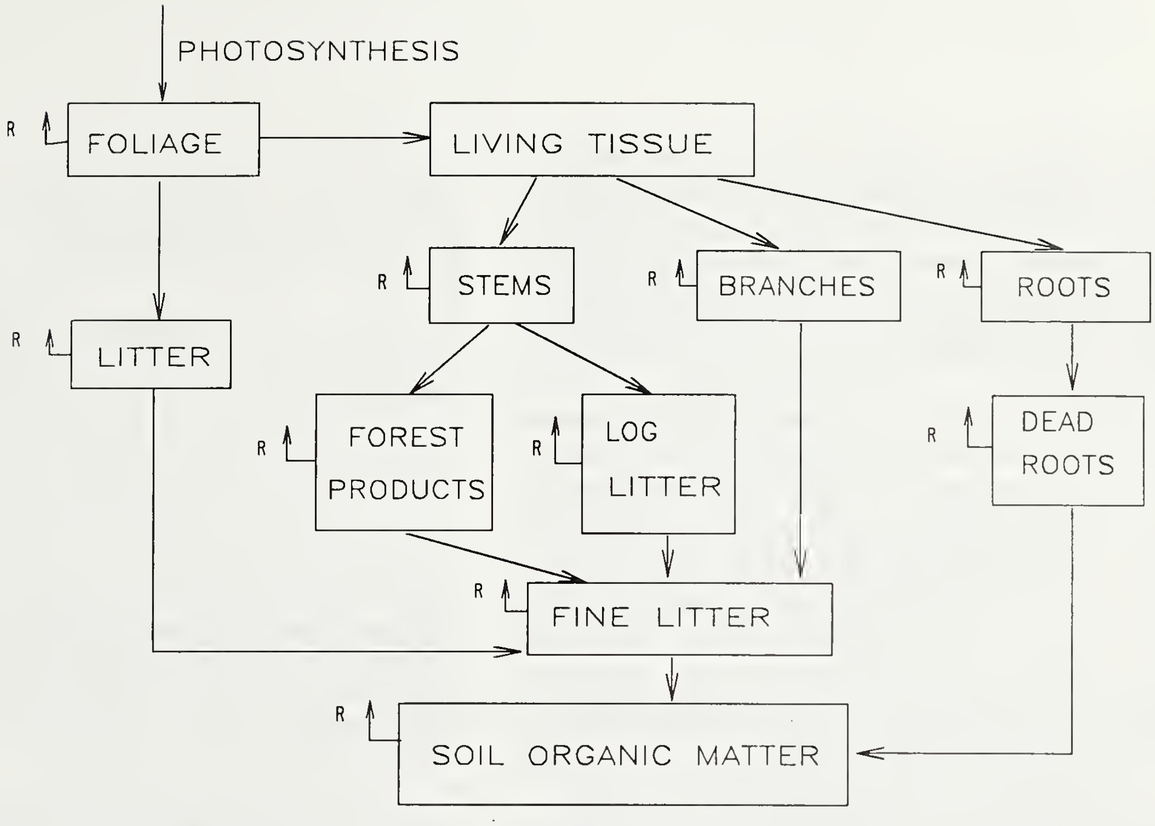


**Figure 1. Generalized carbon budget for a managed forest ecosystem.**

to be derived from other geographic areas. Much work has been done on the carbon budget of summer-dry coniferous ecosystems of the Cascades in British Columbia, Washington and Oregon, and on seral forest types in the Oregon Coast Range (Fujimori 1971, Grier and Logan 1977, Grier et al. 1981, Grier 1976, Turner and Long 1975). On the basis of rainfall and air temperature, perhaps data from studies of the subalpine zone in the Washington Cascades would be most relevant to Southeast Alaska (Grier et al. 1981, Fig 2).

The old-growth forests of the Pacific Northwest are noted for their high accumulations of biomass in massive dominant trees. Aboveground tree biomass frequently ranges from 350 to 750 t C/ha (Waring and Franklin 1980). Old- growth coniferous forests have been shown to be highly productive ecosystems, but with detrital dynamics dominating the production budget. Carbon is cycled quickly in some components (e.g fine litter) but very slowly in the large pools of coarse woody debris and soil organic carbon (Harmon et al. 1986, Sollins 1982, Graham and Cromack 1982). On the Olympic Peninsula, for example, a 37-cm western hemlock and a 54-cm Sitka spruce were estimated to require 241-280 years to completely decompose. Once carbon becomes part of the deeper soil horizons mean residence time may exceed 1000 years, making it a long term sink (e.g. Sollins and Spycher 1983).

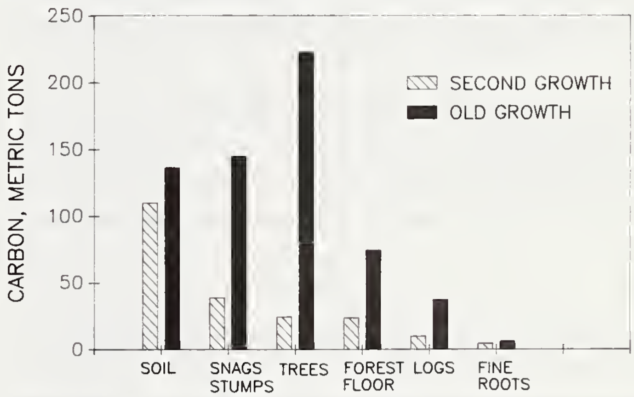


**Figure 2. Biomass distribution of second growth and old groth ecosystems in the Washington Cascades. (After Grier et al. 1981).**

*Southeast Alaska Sites*

Carbon accumulation in forests of Southeast Alaska is generally greater than that reported for deciduous and mixed forest types in the eastern and central United States, but below that reported for sites in the Pacific Northwest (Fig 3, cf. Ovington 1962). The above

ground portions of second- growth trees were estimated to accumulate from 131 to 227 metric tons of carbon per hectare (t C/ha) at 110 years of age, and had a similar ratio of total above ground tree biomass to stemwood biomass as has been reported from other temperate coniferous forests (30-40%, Johnson and Sharpe 1983).

Biomass of old-growth stands is highly variable because of great variation in both soils and sites as well as disturbance history. Well stocked stands on fertile productive sites appeared to accumulate an average of 200 t C/ha, but on exceptional sites could accumulate as much as 300 t C/ha. Poor sites or more disturbed sites accumulated as little as 150 t C/ha. The highest biomass accumulations generally occur within 200-300 years, with a slightly lower biomass accumulation in older age classes (Alaback 1982a).

Several other ecosystem components had significant levels of carbon storage in these stands. Understory vegetation accumulated as much as 2-3 t C/ha and took up 250- 500 kg C $ha^{-1}$ $yr^{-1}$ in old-growth stands (Alaback 1982b). Second growth stands generally had less than 0.05 t/ha understory carbon at maturity. Logs contained 20 t C/ha on a relatively unproductive old-growth site. Productive sites would be expected to accumulate at least double this carbon pool (Harmon et al. 1986).

Soil carbon (not including tree roots) means vary from 529 t C/ha in poorly drained sites to 298 t C/ha on well drained sites to 174 t C/ha on shallow soils (Alexander et al., 1989). Presumably the cool wet climate and lower respiration and decomposition rates explain why the pool of soil carbon in Southeast Alaska is 2-4 times that of even the subalpine sites in the Pacific Northwest. Just on the basis of temperature, and assuming a $Q_{10}$ of 2 one would expect decomposition to be about half that of coastal sites in the Pacific Northwest (Farr and Harris 1979).

It is generally assumed that the majority of soil carbon is derived from the turnover of fine roots (e.g. Grier et al. 1981). Despite the magnitude of their importance to the carbon budget, relatively little information is available about below ground ecosystem processes in general, and even less has been published about temperate rainforest ecosystems.

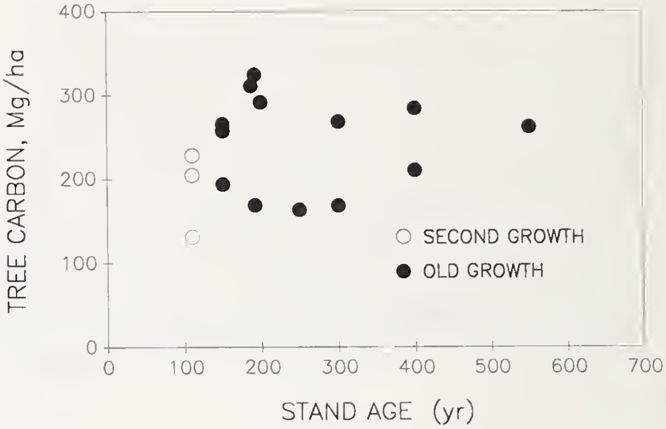


**Figure 3. Aboveground tree carbon for mature second growth and old forests in Southeast Alaska. Second growth biomass estimates represent means stratified by site class (Site Index 70,110, and 150, Taylor 1934).**

*Changes in Carbon Storage With Logging*

With disturbance (logging) it is assumed that decomposition and respirational losses of tree roots, foliage, branches, other nonmerchantable material and soil carbon will initially increase net $CO_2$ emission. Preliminary data on decomposition of filter papers suggest a dramatic increase in litter decomposition rates following clearcutting in Southeast Alaska, probably due to elevated soil and litter temperatures during the growing season (Alaback and Bormann, unpublished data). Filter papers average 75% consumption within a year on clearcuts as constrasted with 10-20% in typical forested sites. Instantaneous readings of litter (2 cm depth) and soil temperature (10 cm depth) in recent clearcuts suggested maximal temperature increases of 10°C and 3°C respectfully. In windthrow gaps soil temperatures only increase 0-2°C (Alaback 1989).

In other temperate forest types 25-60% of soil carbon is typically lost following logging, depending on the extent of initial disturbance (Aber et al. 1978, Boone et al. 1988, Delcourt and Harris 1980, Harvey et al. 1981, Ovington 1962, Schlesinger 1977, Vitousek 1983). Highest carbon losses usually occur in the warmest climates and on well drained sites (e.g. Schlesinger 1977). The poorly drained sites in Southeast Alaska, for example would be expected to lose the least forest floor and soil carbon, unless the soils were highly disturbed.

Uptake of carbon from shrubs and trees usually overtakes the rate of carbon loss following canopy closure (e.g. Aber et al. 1978). At these early stages of ecosystem recovery, biomass accretion and leaf area are usually at their peak (Alaback 1982a, Grier et al.

1981, Odum 1969). Following canopy closure, litter decomposition rates generally decline (Turner and Long 1975, Aber et al. 1978). Net primary productivity and leaf area usually decline then stablize for the remainder of the life of the forest.

Large accumulations of carbon in the forest floor and soils of most old-growth forests may be a result of a long history of low intensity disturbances and continuous forest cover (Cromack et al. 1979, Grier and Logan 1977, Grier et al. 1981, Sollins and Spycher 1983). It has been hypothesized that under the cool wet climate of Southeast Alaska, forest soils normally degrade into organic soils or bogs unless periodic disturbance reverses these successional trends (Ugolini and Mann 1979, Bormann unpublished). Since clearcutting opens up the site and allows accelerated litter decomposition over that typically experienced under old- growth conditions a net loss of carbon from these thick organic horizons (and a new lower equilibrium for soil carbon storage) may be a logical outcome of the conversion of old-growth to cropped second-growth forests. In most forest types the conversion of old-growth to managed second growth has resulted in a net emission of soil carbon emission to the atmosphere (Delcourt and Harris 1980, Vitousek 1983).

The primary consequence of logging on the carbon cycle is the decrease in mean residence time of carbon in logs and trees (Cromack et al. 1979, Delcourt and Harris 1980, Vitousek 1983, Fig. 1). In temperate rainforests most of the wood from old-growth and virtually all of the wood from second-growth forests is used for pulp, paper or chemical products. In Southeast Alaska roughly 50% of the harvested wood is processed for pulp the rest being used for more durable products (Michael Fosberg, USFS Washington, D.C., pers comm.). Under the best conditions only 50 percent of the fiber is recovered in the pulping process, and in Southeast Alaska 30-40 percent recovery is considered more realistic. Since these products tend to be short lived, and their carbon content is usually lost to the atmosphere either through burning or decomposition in landfills essentially all of the carbon associated with merchantable material might be considered a short-term emission to atmosphere. The net effect of timber harvesting might then be viewed as changing the mean residence time of carbon in logs from 200-300 years or more in old-growth forests to the mean lifespan of forest products. In the southeastern US the management of pines for pulpwood is similarly considered a net carbon emmission to the atmosphere due to the short lifespan of these forest products (Cooper 1983, Schiffman and Johnson 1989).

In some old-growth forest types, in which carbon is accumulated by dominant trees for long periods of time, second-growth forest biomass may not reach that of the old- growth forest within a typical 100 year rotation. For example, 1000-1500 year old redwood *Sequoia sempervirens* forests can accumulate over 1700 t C/ha (Fujimori 1977). Old growth western redcedar (*Thuja plicata*) are also likely to accumulate more biomass in the old-growth condition (often > 1000 years) than in 100 year old second growth stands.

Logging of temperate rainforests in the southern hemisphere (principally the southern portions of Chile, New Zealand, and Australia) probably contributes more carbon to the atmosphere per ha than do forestry practices in the northern Pacific rainforest. Wood biomass alone of alerce (*Fitzroya cupressoides*) forests 1000-3000 years old in the temperate rainforests of southern Chile was estimated to comprise from 400 to over 900 t C/ha (Donoso 1987). Second growth stands 80 years old typically accumulate only 162-240 t C/yr (Ingeniera de Bosques 1975). Thus conversion of the more massive old-growth forest stands to second-growth may lead to significantly reduced tree carbon pools. Much of the logging in the southern hemisphere also leads to the conversion of forest to agriculture, and the use of fire, further excerbating carbon emissions (Veblen 1976, Vitousek 1983).

Compared with other forest types, land use practices in the temperate rainforest zone probably have little effect on global atmospheric carbon. The relatively small land area, and high degree of deforestation which has already occurred in the more productive lower latitudes limits the potential impact of forest practices in this zone. The high rate of reforestation, and cool climate should also minimize net carbon emissions with respect to the tropics and continental temperate climatic zones.

*Research Needs*

More basic process oriented ecosystem research is needed to assess the impacts of land-use practices on atmospheric carbon in the temperate rainforest zone. Although reasonable estimations of standing crop biomass of trees can be made, the processes regulating net carbon flux, principally those below ground are a major area of uncertainty. The unique climatic setting of Southeast Alaska and other cool temperate rainforests may result in less change in soil respiration and decomposition rates following timber harvest, relative to forest types that have been studied. Relatively little data is available on the effects of timber harvest and site preparation techniques on microclimate or decomposition in any of the temperate rainforest regions.

A key question for future research will be how the production budget of old-growth and second-growth forests varies across the full mosaic of soil and microclimatic conditions throughout the temperate rainforest zone. Relatively little is known about the response of marginal sites (both poor soils and higher elevations) to forest management, both in terms of regeneration, tree growth, and carbon distribution. At the very least, baseline information on ecosystem biomass distribution and productivity on a few typical old-growth and mature second growth sites is needed for regional comparisons.

To definitively assess the net effect of forest management on atmospheric carbon more information will be needed on the fate of wood harvested from old-growth and second-growth forests, and on the decomposition rates of large woody debris in the forest. Predictions of future changes in wood utilization, and silvicultural practices will also have to be included in any assessment of the effects of forest management on atmospheric $CO_2$. Last but not least, considerably more detail and realism is needed in the global atmospheric models before a high degree of confidence can be placed on the ultimate role of land-use practices on global climatic trends.

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# Soils of Southeast Alaska as Sinks for Organic Carbon Fixed From Atmospheric Carbon-Dioxide

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***Abstract.*** More organic carbon is stored in soils than in living biomass. Although there is little difference in the sizes of these two pools in most forests of southeast Alaska, most very poorly drained soils contain much more organic C than the vegetation on them. The mean organic C contents of Folists, shallow soils, deep inorganic soils, Lithic and Terric subgroups of Histosol great groups, and deep Histosols (organic soils) are 15, 17, 29, 53, and about 120 kg/m², respectively. Organic C accumulates at about 90 g/m² each year during the alder stage of succession on glacial moraines and then approaches a steady state as early stages are succeded by coniferous forest. It has accumulated at an average rate of 29 g/m² in muskegs of southeast Alaska over the past 10 000 years. There are 1.233 10⁹ Mg of organic C in the soils of 42 292 km² mapped on the Tongass National Forest, 39% of the area in southeast Alaska. The average soil organic C in this mapped area, thus, is 28 kg/m², compared to a world mean of 10 kg/m². It is increasing, because (1) many glaciers in southeast Alaska are receding, exposing more land to colonization by plants, and (2) organic matter continues to accumulate in Histosols, which cover about one-quarter of the land in southeast Alaska.

Plants take $CO_2$ from the atmosphere to produce organic matter (Fig. 1). They consume some of that organic matter in respiration and store some in tissues. When leaves and dead plants fall to the ground, their tissues are incorporated into the litter layer by small animals and microorganisms. Plant roots shed tissues and decay below ground, adding organic matter directly to soils. A balance is maintained between organic matter additions and losses by decay in many soils, while organic matter accumulates in the litter layers of others. Soils with surface organic material accumulations thicker than 40 to 60 cm, depending on the fiber content or bulk density, are called organic soils (Soil Survey Staff, 1975).

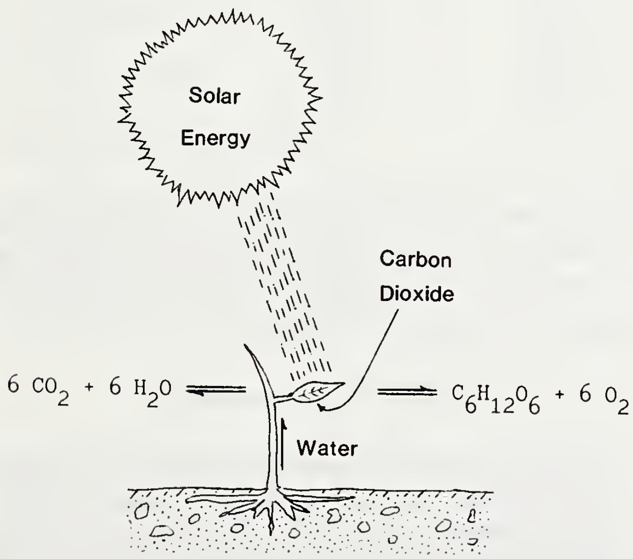


**Figure 1. A simplified equation representing the fixation of organic C in carbohydrates by photosynthesis. The reverse reaction is a simplified representation of respiration.**

Generally, there is more organic carbon in soils and ground litter layers than in live and standing biomass (Schlesinger, 1977). Thus, the soil is an important organic carbon sink; it is a buffer of atmospheric $CO_2$ fluctuations (Houghton et al., 1983) and consequent climatic changes. Soil organic carbon accumulations are greatest in wet polar and alpine areas followed closely by very wet boreal and subalpine areas (Post et al., 1982). The data, however, are inadequate for accurate estimates of organic carbon stored in the soils of these areas. Billings (1987) has made a recent contribution to estimates for polar and subpolar areas. In this article, we report the utilization of Tongass National Forest soil resources inventory data to estimate organic carbon storage in the soils of perhumid cold (maritime-boreal) southeast Alaska.

## Methods

Thousands of pedons have been described in southeast Alaska. A few hundred of them have been sampled for laboratory analyses. The majority of those samples were sent to the National Soil Survey Laboratory in Lincoln, Nebraska, where organic C was determined by a modified Walkley-Black procedure (Soil Survey Staff, 1984). Some samples were sent to University

of Idaho and Oregon State University laboratories, where organic C was determined by similar procedures.

Undisturbed (core or clod) samples were collected in southeast Alaska only in the Haines Soil Survey Area. Bulk density equations developed from data on those samples and on undisturbed samples from other southern Alaska soils (Alexander, 1989) were utilized to convert organic C/mass to C/volume in inorganic soil horizons.

The bulk densities of organic layers are closely related to fiber contents (Boelter, 1969); thus, the bulk densities of organic horizons were assumed to be 0.06 $Mg/m^3$ for fibric, 0.10 $Mg/m^3$ for hemic, and 0.12 $Mg/m^3$ for sapric materials (Lynn et al., 1974). These values span the range of bulk densities in muskegs sampled by Sellmann (1968) in southeast Alaska. Organic layers with bulk densities greater than about 0.2 $Mg/m^3$ generally contain inorganic particles. Inorganic particles of fine-earth (particles < 2 mm) reduce the gravimetric organic matter content but have little effect on the volumetric organic matter content of organic layers (Gosselink et al., 1984; Lynn et al., 1974). Therefore, the organic C contents of organic layers were based on layer thicknesses and assumed bulk densities for mineral-free organic materials, ignoring inorganic particle contents.

The organic C content of organic matter in organic layers increases as the organic matter decomposes (Clarke, 1924). Based on Clarke's data and similar values reported by Fuchsman (1980), C contents were assumed to be 0.50 g/g in fibric, 0.56 g/g in hemic, and 0.60 g/g in sapric materials. The volumtric organic C contents of organic layers were computed from (1) the assumed bulk densities of the organic materials and (2) the assumed organic C contents of the materials (Table 1).

**Table 1. Properties of organic materials assumed in order to compute volumetric organic C contents.**

| -------Horizon------ | | Bulk Density | ---------Organic C Content--------- Gravimetric | Volumetric |
|---|---|---|---|---|
| Name | Symbol | $Mg/m^3$ | kg/kg | $kg/m^3$ |
| Fibric | Oi | 0.06 | 0.50 | 30 |
| Hemic | Oe | 0.10 | 0.56 | 56 |
| Sapric | Oa | 0.12 | 0.60 | 72 |

Soils were grouped by taxonomic class (Soil Survey Staff, 1975) to determine, utilizing Student's t-test, which have similar and which have significantly different organic C contents. The areal distributions of soil classes for which organic carbon contents were estimated were determined from soil data in a geographical information system which is ultilized primarily for land management planning.

Heusser (1952;1954) has described materials from 20 holes in muskegs of southeast Alaska. Four of the soils appear to be either Terric or Lithic Cryosaprists. The mean organic C in the 16 other Histosols is 238.6 $kg/m^2$ (Table 2). Since Heusser reported only the deepest profiles in each muskeg he sampled, this value was divided by 2 to yield 120 kg $C/m^2$ as an estimated mean to utilize in the computations of soil organic C in the soil survey areas of southeast Alaska.

## Results and Discussion

Most of the soils in forests of southeast Alaska are Spodosols and those in muskegs are Histosols (organic soils). Initially the soils were aggregated into 10 groups (Table 2). We have abundant data on Spodosols, but insufficient pedons with organic C data in some groups

**Table 2. Organic carbon in pedons (soil profiles) with laboratory data and in the deeper 16 (depth > 1.35 m) of 20 muskeg profiles sampled by Heusser.**

| Part of Pedon | Mean Organic C | Standard Deviation | Coef. of Variation | |
|---|---|---|---|---|
| | --------------kg/m²-------------- | | fraction | |
| shallow Entisols and Inceptisols, 1 alpine pedon | | | | n= 7 |
| O-horizon | 8.8 | 5.1 | 0.58 | |
| regolith | 8.1 | 5.0 | 0.62 | |
| total | 16.9 | 4.8 | 0.28 | |
| deep Entisols and Inceptisols, 2 in alluvium | | | | n= 7 |
| O-horizon | 7.2 | 3.2 | 0.45 | |
| regolith | 25.2 | 10.4 | 0.41 | |
| total | 32.4 | 11.1 | 0.34 | |
| shallow (including Lithic) Spodosols | | | | n=26 |
| O-horizon | 8.6 | 3.9 | 0.46 | |
| regolith | 8.8 | 6.0 | 0.68 | |
| total | 17.4 | 7.4 | 0.42 | |
| deep Aquods | | | | n=14 |
| O-horizon | 6.9 | 4.9 | 0.71 | |
| regolith | 18.6 | 4.9 | 0.26 | |
| total | 25.5 | 4.6 | 0.18 | |
| deep Spodosols other than Aquods | | | | n=95 |
| O-horizon | 8.4 | 4.8 | 0.57 | |
| regolith | 21.4 | 9.7 | 0.46 | |
| total | 29.8 | 10.3 | 0.35 | |
| Lithic Cryofolists | | | | n= 9 |
| total | 15.0 | 6.1 | 0.41 | |
| Typic Cryofolists | | | | n= 4 |
| total | 14.2 | 4.2 | 0.30 | |
| shallow Lithic Cryosaprists | | | | n= 1 |
| total | 19.4 | | | |
| deep Lithic and Terric Cryosaprists (including 1 Cryohemist) | | | | n= 4 |
| total | 52.9 | 11.7 | 0.22 | |
| organic soils (Histosols) in muskegs | | | | |
| organic | 238.6 | | | n=16 |

of soils to separate them from other groups. Statistically, no more than 4 groups are justified (Table 3): (1) 43 shallow soils (regolith < 0.5 m) with a mean of 17 kg C/m², (2) 116 deep inorganic soils with a mean of 29 kg C/m² to depths of 1.5 m in alluvium or 1.0 m in other kinds of regolith, (3) 4 Lithic and Terric Cryosaprists (including 1 Cryohemist) with 53 kg C/m² within the control sections (above 1.3 to 1.6 m), and (4) deeper organic soils with much more organic C. The mean of 4 Typic Cryofolists (Table 2) is not significantly different from that for the shallow soils, but the Cryofolists were treated as a fifth group anyway. We added a sixth group for rock outcrop and other miscellaneous landtypes with negligible amounts of organic C. Organic debris which has accumulated in terrestrial aquatic ecosystems was not considered in this study.

**Table 3. Comparisons of organic C means for each combination of 2 soil groups. Absolute values of Student's t appear on the lower left and the numbers of degrees of freedom appear on the upper right of the table.**

| ------Entisols------- | | ---------Spodosols----------- | | | ---Cryofolists--- | | Lithic and Terric Cryosaprists |
|---|---|---|---|---|---|---|---|
| shallow | deep | shallow | Aquods | deep | Lithic | Typic | |
| -- | 12 | 31 | 19 | 100 | 14 | 9 | 9 |
| 3.39* | -- | 31 | 19 | 100 | 14 | 9 | 9 |
| (0.17) | 4.28* | -- | 38 | 119 | 33 | 28 | 28 |
| 3.99* | (2.04) | 3.73* | -- | 107 | 21 | 16 | 16 |
| 3.27* | (0.64) | 5.74* | (1.53) | -- | 102 | 97 | 97 |
| (0.67) | 4.02* | (0.88) | 4.72* | 4.23* | -- | 11 | 11 |
| (0.93) | 3.10 | (0.84) | 4.42* | 3.00* | (0.24) | -- | 6 |
| 7.36* | 2.90 | 8.31* | 7.41* | 4.37* | 7.87* | 6.24* | -- |

Values in parentheses, insignificant (p>0.05); *, highly significant (p<0.01).
Although 0.01 was assumed to be the maximum acceptable probability of a Type I error, it is actually somewhat higher utilizing the t-test in multiple comparisons (Steel and Torrie, 1980).

**Table 4. Distribution of soils and organic C stored in them on the 3 Areas of the Tongass National Forest.**

| Soil Group | Org. C Content | ----------------Area of Soil Group---------------- | | | | | | Sum of Areas | |
|---|---|---|---|---|---|---|---|---|---|
| | | Chatham Area | | Ketchikan | | Stikine Area | | | |
| | kg/m² | km² | % | km² | % | km² | % | km² | % |
| Folists | 15 | 673 | 4 | 1 160 | 9 | 49 | <1 | 1 882 | 4 |
| Shallow Soils | 17 | 4 801 | 29 | 3 082 | 23 | 4 808 | 36 | 12 691 | 29 |
| Deep Inorganic | 29 | 4 463 | 27 | 3 944 | 30 | 2 621 | 19 | 11 028 | 25 |
| Lithic & Terric | 53 | 1 239 | 7 | 3 496 | 27 | 1 452 | 11 | 6 187 | 14 |
| Deep Organic Soils | 120 | 873 | 5 | 262 | 2 | 1 713 | 13 | 2 848 | 7 |
| Rock, Snow, Ice | | 4 503 | 27 | 756 | 6 | 2 319 | 17 | 7 578 | 18 |
| Freshwater Bodies | | 207 | 1 | 339 | 3 | 532 | 4 | 1 078 | 3 |
| | | 16 759 | | 13 039 | | 13 494 | | 43 292 | |

*Areal Distribution of Soil Organic C in Southeast Alaska*

Soil surveys were conducted independently on the 3 Areas of the Tongass National Forest (Fig. 2). Ground areas were compiled by soil group for each of the 3 Areas (Table 4). The distributions are quite different among Areas. These Areas represent 39% of the 110 000 km² in southeast Alaska. The total organic C is 1.233 $10^9$ Mg in these Areas. It cannot be extrapolated to the rest of southeast Alaska, because the remainder contains the Malaspina Glacier, the largest in noninsular North America, and the Glacier Bay National Park, which has a large portion of permanent snow and ice.

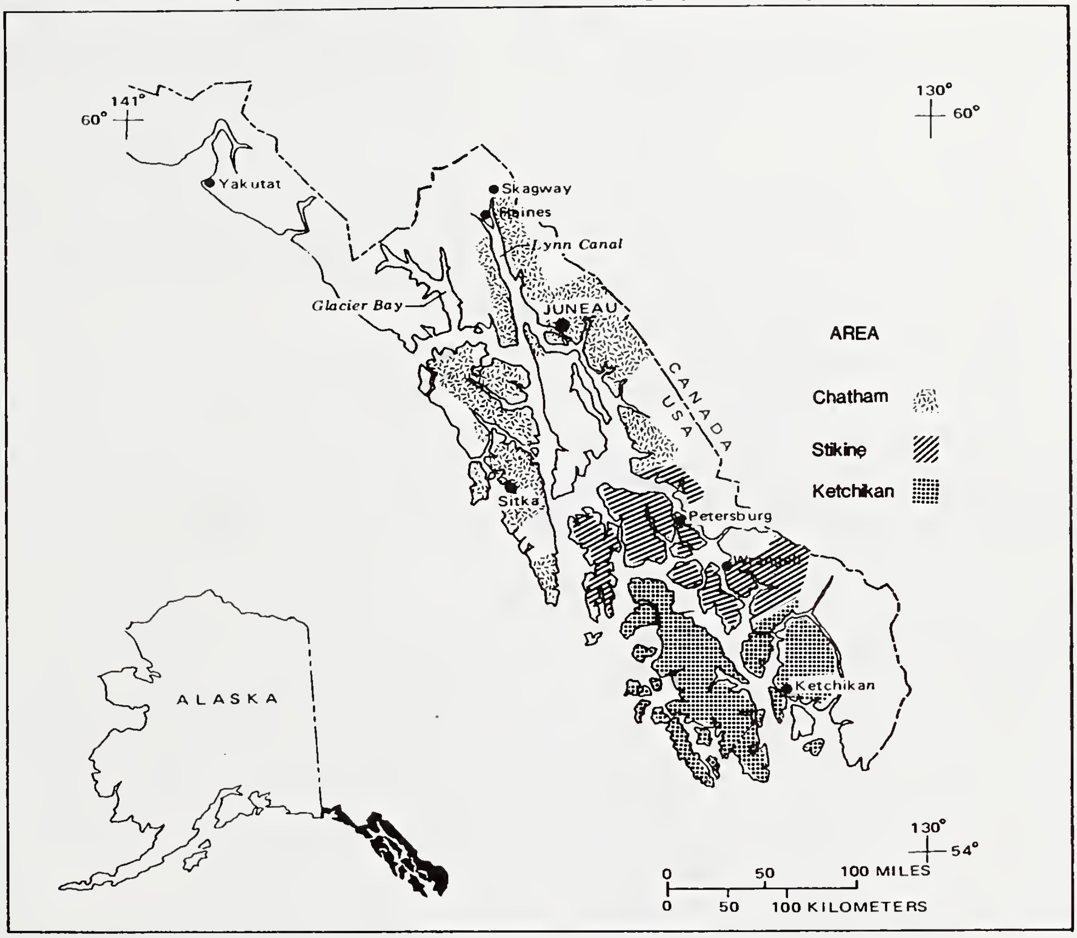


**Figure 2. Soil survey areas where areas were determined to obtain the data in Table 4.**

*Rates of Soil Organic C Accumulation in Soils of Southeast Alaska*

Soils have been studied in 4 different glacial moraine sequences in southeast Alaska (Table 5). The rates of organic C accumulation are greatest in the alder stage of plant succession, on the order of 90 g/m² each year. At that rate, it would take 190 to 320 years to reach the means for shallow or deep inorganic soils, respectively (Table 2). Since the rates decline as conifers replace alders, however, it would take considerably longer to reach a steady state.

Twenty muskegs sampled by Heusser (1952; 1954) have depths up to 5.9 meters. All of those over 4 m deep have soil organic C contents about 290 kg/m² (Fig. 3). The deeper muskegs are on the order of

10 000 years old (Heusser, 1958). Thus, the average rate of accumulation has been about 29 g C/m² each year. Several studies in northwestern Europe indicate that peat has generally accumulated at rates of 0.4 to 0.8 mm/yr (12 to 25 g C/m² yr), or less, over the last 2 500 years (Barber, 1981). Durno (1961) reported variable rates of peat growth in the British Isles over the last 10 000 years, but mostly within the range from Barber (1981). Thus, rates of peat accumulation vary considerably over both space and time. Apparent rates of accumulation may be confounded by compaction (Aaby and Tauber, 1975). The highest rates of peat accumulation are reported from the arctic, where they were 0.7 to 1.5 mm/yr (21 to 45 g C/m² yr) between 10 000 to 5 000 years ago (Tarnocai and Zoltai, 1988).

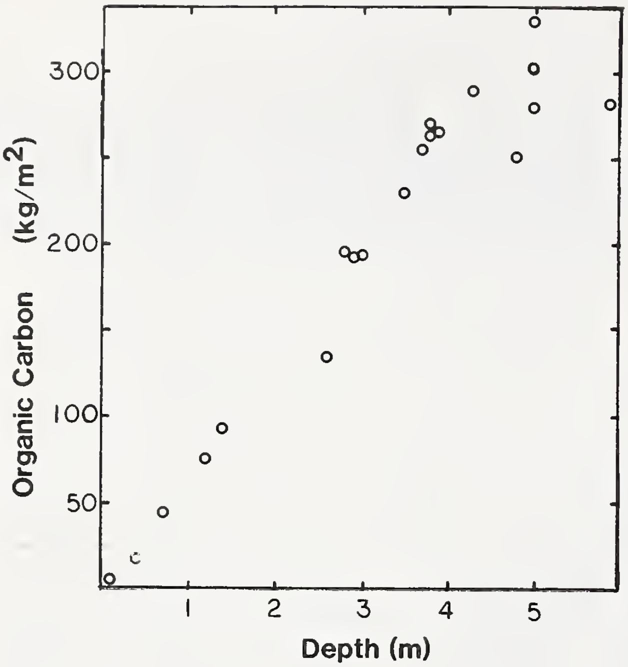


**Figure 3. Soil organic carbon in relation to depth of muskegs in southeast Alaska (Heusser, 1952 and 1954).**

**Table 5. Rates of organic C accumulation in soils of southeast Alaska.**

| Location | Data Source | Successional Stage | | Organic C[1] Increment |
|---|---|---|---|---|
| | | yr | | g/m² yr |
| Glacier Bay | Crocker & Major (1955) | 10-30 | alder | 92 |
| Glacier Bay | Ugolini (1968) | 5-55 | alder | 113 |
| Mendenhall Glacier | Crocker & Dickson (1957) | 10-50 | alder | 91 |
| Herbert Glacier | Crocker & Dickson (1957) | 10-50 | alder | 72 |
| southeast Alaska | Heusser (1952; 1954; 1958) | 10 000 | muskeg | 29 |

[1] Rate of organic C accumulation in soil plus forest floor.

*A Global Perspective*

The total soil organic carbon storage is about 1.5 $10^{12}$ Mg world-wide (Meentemeyer et al., 1985), compared to 0.8 or 0.9 $10^{12}$ Mg in terrestrial biomass (Whittaker and Likens, 1975), depending on the C content of the biomass. The mean soil organic C is 10 kg/m². The mode is considered to be about 21 kg/m² in very wet boreal areas (Post, et al., 1982), being higher only in tundra areas. More soils have organic C contents above the mode than below it. The means are 23, 31, and 33 kg/m² in the Chatham, Ketchikan, and Petersburg Areas. These organic C contents are higher than the mode for soils of very wet boreal areas (Post et al., 1982) due partly to the inclusion of O-horizons on inorganic soils and partly to the large extent of organic soils in southeast Alaska. The mean would undoubtedly be reduced if unmapped areas of southeast Alaska were considered, due to the large portion of permanent snow and ice in these areas.

The total organic carbon stored in the soils of southeast Alaska is increasing, because (1) the majority of the glaciers in southeast Alaska are receding and (2)

organic C continues to accumulate in the Histosols, which cover about 25% of the mapped area (Table 4). Organic carbon accumulates rapidly as glaciers recede and plants colonize the exposed glacial drift. Although small areas of forested inorganic soils lose organic matter temporarily, following disturbance, there is no evidence of net loss from the forested soils of southeast Alaska. There is practically no agriculture, nor any domestic grazing, and logged areas are quickly revegetated, unlike cleared areas in some parts of the world.

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## Southeast Style

To manage in Southeast
You must use all the tools.
First inventory, then classify
and follow all the rules.

Which is common?
Which is rare?
That's a problem here.
And if the road gets too rough,
Just let out a little air.

"What's that", you ask of Paustian,
"A1, C2, B3 ?"
And could it be Riparian
With Large Organic Debris ?

When all the data have been collected
or just obtained by guess,
You "jolly well better" think it through,
'Fore you give it to the G. I. S.

Were ready now to manage
If there are no more complaints.
And if there are, that's no problem,
We'll just call them our constraints !

Yes, were ready now to manage
For non-ugliness and wood,
For brown bears and fish,
Do you think we could ?

Oh yes! Of course ! We can, we can.
We can do anything,
We've got FORPLAN !

Now you may laugh or you may steam,
Call me some unkind name.
But I've been impressed, you're all good people,
And good Stewardship is your aim.

GPO 694-480/00074